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WIDEBAND LASER COMMUNICATIONS

An Annotated Bibliography

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261 highly specific abstract/citations on the subject of Wideband Laser Communications make up this bibliography. To our knowledge, this the first such effort to narrow down the bibliographic identification of this important aspect of laser technology. Journal articles, books, and government reports have been chosen for inclusion from abstracts appearing in the NASA STAR, TAB, U.S.G.R.D.R., and IAA. Coverage was for the years 1964-1970. Citations are arranged alphabetically by author. Among the subjects covered are: optical communication at high data rates, optical beam acquisition and fine tracking, and atmospheric effects on laser beam propagation.

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261 highly specific abstract/citations on the subject of Wideband Laser Communications make up this bibliography. To our knowledge, this the first such effort to narrow down the bibliographic identification of this important aspect of laser technology. Journal articles, books, and government reports have been chosen for inclusion from abstracts appearing in the NASA STAR, TAB, U.S.G.R D.D., and IAA. Coverage was for the years 1964–1970. Citations are arranged alphabetically by author. Among the subjects covered are: optical communication at high data rates, optical beam acquisition and fine tracking, and atmospheric effects on laser beam propagation.

LOCKHEED PALO ALTO RESEARCH LABORATORY
LOCKHEED MISSILES & SPACE COMPANY
A GROUP DIVISION OF LOCKHEED AIRCRAFT CORPORATION

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FOREWORD

The potential importance of a coherent optical beam as a carrier for communication at extremely high data rates was recognized almost immediately after the invention of the laser. Since then, much effort has been expended on the development of the technology and components needed for practical realization of this potential. However, only recently has this development reached the point that it has become possible to seriously consider implementing laser communication links capable of information bandwidths above a few tens of MHz or, correspondingly, data rates of 100 Mbits/sec or more; data rates of at least 1,000 Mbits/sec are now feasible and much higher data rates are coming within reach.

This bibliography is intended primarily as a guide to the literature dealing with the problems of and technology for optical communication at data rates above 100 Mbits/sec. However, numerous entries of a more general nature were included when they appeared to be applicable to the high data rate case. Also, the bibliography covers the subjects of optical beam acquisition and fine tracking. The precision with which these functions must be performed may be several orders of magnitude greater than that achievable with techniques that have been developed for microwave communication links.

Finally, references on atmospheric propagation effects have been included because communication between space vehicles and/or mobile ground stations was a primary interest. For the same reason, the subject of guided wave propagation was excluded.

1. Advisory Group for Aerospace Research and Development, Paris, France
OPTOELECTRONIC COMPONENTS AND DEVICES. Proceedings of the 9th Meeting of the AGARD Avionics Panel held in Paris, France, 6–9 Sep 1965. Sep 1965, 446p.
Rept. no. AGARD-CP-5. AD-804 361.

2. Air Force Systems Command, Foreign Technology Division, Wright-Patterson AFB, Ohio
EXPANSION OF OPTICAL WAVES IN THE ATMOSPHERE. Unedited rough draft translation, by M. Miler. Trans. of Jemna Mechanika A Optika n10 p313–317, 1965. 5 Dec 1966, 20p.
Rept. no. FTD-HT-66-341. AD-808 298.

Atmospheric properties are discussed in detail from the viewpoint of the effect of the atmosphere on optical wave propagation. Individual causes of the origin of optical wave damping and noise damping are cited and data is presented on the magnitude of damping in various parts of the spectrum. Atmospheric properties are then evaluated from the standpoint of using optical waves for relative purposes.

3. Air Force Systems Command, Foreign Technology Division, Wright-Patterson AFB, Ohio
EXTERNAL LIGHT MODULATION BY MEANS OF THE POCKEL EFFECT, by H. Schroeter. Edited trans. of Nachrichtentechnik (East Germany) v18, n5, p177–178, 183–185, 1968. 27 Feb 1970, 17p.
Rept. no. FTD-HT-23-462-69; Proj. FTB 7230178.
AD-867 676.

A theoretical discussion is given of the most important methods than can be realized by means of crystals exhibiting the linear electrooptical effect. Although this effect (the so-called Pockels effect) has been known for some time, its potential for external light modulation has not been considered so far. After describing the basic fundamentals involved, the author describes amplitude modulation with suppressed carrier, amplitude modulation with nonsuppressed carrier, and pulse modulation.

4. Alley, C. O. and D. G. Currie
LASER BEAM POINTING TESTS. Maryland Univ., College Park, Dept. of Physics and Astronomy, College Park, Md. Jun 1968, 11p. (Grant NGR-21-002-019). (NASA-CR-97924; TR-885). N69-13247.

An opportunity to verify the ability of earth stations for directing very narrow laser beams to a specific location on the lunar surface was provided by the detection sensitivity of the Surveyor VII vidicon camera operating in its integration mode. Such tests were of interest primarily because of a planned Apollo lunar surface experiment in which an astronaut will emplace a corner reflector array to provide a fixed point for very precise laser ranging. Estimates of the power density on the moon of a 10-W (transmitted) argon-ion laser beam contained within a divergence cone angle (half) of 10 sec of arc yielded a value 2.25 times the power density of a magnitude O star, or nearly magnitude − 1. The power density would scale directly as the power transmitted and inversely as the square of the beam angle. Experience with star observations on previous Surveyor missions indicated that the laser beam could be easily observed if they were directed to illuminate the spacecraft. The diameter of the illuminated area on the moon is about 2 km per arc second of divergence.

5. Alley, C. O. and D. G. Currie
LASER BEAM POINTING TESTS. National Aeronautics and Space Administration, Washington, D.C. IN: Its Surveyor Program Results, 1969, pp. 397−403. N69-36462.

The potential value of well collimated laser beams for space communications is studied through the detection sensitivity of the Surveyor 7 vidicon camera operating in its integration mode. Argon-ion laser beams were directed backward through a telescope from five ground stations towards the Surveyor camera after lunar touchdown. Detection of on-off sequenced laser beam spots was confirmed by subsequent correlations of projected enlargements from photographic negatives reproduced from video tape recordings at the ground flight operations facility. One watt collumated laser beams appear as bright stars, while the uncollimated light from major cities is not detected.

6. Anderson, R. F.
STUDY AND INVESTIGATION OF ACQUISITION AND TRACKING OF OPTICAL COMMUNICATION SYSTEMS. Philco Corp., Blue Bell, Pa. Final rept. for 1 Jun 1961–30 Jun 1962. Nov 1962, 327p. (Rept. no. 9036-F). (Contract AF 33 (616)8392. (ASD TDR 62-733). AD-293 452.

Acquisition and tracking as applied to representative optical communication systems are studied. The two hypothetical communication links considered were between an earth-orbiting satellite and a moon-orbiting satellite, and between an earth-orbiting satellite and a cislunar space vehicle. The results show that acqusition and tracking are feasible. The study includes a typical system design based on the use of a laser communication transmitter. This subsystem utilizes a five-motor gimbal configuration which mounts the optical systems and sensors that perform the far-body tracking function and the acquisition and tracking of the communication beam. An image tube is used as the acquisition sensor in order to obtain high scanning rates. The tracking sensor design is based on state-of-the-art star trackers and utilizes a muliplier phototube.

7. Antypas, G. A. et al.
IMPROVED PHOTOCATHODES FOR 1.6 MICRON DETECTION USING $GaAs_{1-x}Sb_xCs_2O$. Fourth Conference on Laser Technology, San Diego, Jan 1970, Vol. 1, p. 437.

Quantum efficiencies of 0.27% at 1.06 micron have been obtained from a $GaAs_{0.86}Sb_{0.14}$ photocathode. The material was grown by liquid epitaxy on GaAs substrates and coated with a Cs_2O layer to reduce the work function. A semitransparent yield of 0.013% at 1.06 micron has been obtained by growing a thin layer on a semi-insulating GaAs substrate. Methods of growth and a theoretical model for the behavior of the cathode are also described.

8. Arams, F., W. Chiou, and T. Flattau
BROADBAND OPTICAL RECEIVER FOR 10.6 MIRCONS. Final technical rept. Feb–Nov 1969. Rept. no. RADC-TR-70–77, AIL-8216-1. May 1970, 29p. Contract F30602-69-C-0216. AD-871 622.

A packaged infrared 10.6 micron heterodyne receiver was developed for radar application. It combines sensitivity approaching the quantum-noise limit with gigahertz IF bandwidth. Signal processing electronics was also provided for search and acquisition of the doppler-shifted radar return signal, and other functions. The receiver has as its principal components a cryogenically cooled Ge:Cu infrared mixer element, and associated broadband IF preamplifier, IF and signal processing electronics, and peripheral monitor and control electronics. The receiver is suitably packaged for operational use in a 10.6-micron pulsed radar system. Design consideration and measured receiver characteristics are presented. Receiver noise properties for IF frequencies up to 1200 MHz and mixer noise characteristics were measured. The measured noise equivalent power was 8.1×10 to the minus 20th power w/Hz at 1.4 kHz, less than 1.5×10 to the minus 19th power w/Hz from 10 to 800 MHz, and less than 2.25×10 to the minus 19th power w/Hz up to 1200 MHz.

9. Armington, A. F. and J. J. O'Connor
TRANSVERSE MODE ELECTRO-OPTIC MATERIALS. Air Force Cambridge Research Labs., L. G. Hanscom Field, Mass. Physical sciences research papers, Jan 1970, 21p. Rept. nos. AFCRL-PSRP-402, AFCRL-70-0005. Presented at the Avionics Panel, Technical Symposium (17th) Tonsberg (Norway) 29 Sep 1969. AD-700 049.

Most electro-optic modulators presently used are crystals such as KDP which exhibit a longitudinal electro-optic effect. It has been demonstrated that a more efficient modulator can be produced when a crystal having a transverse electro-optic effect is employed. Generally these crystals are produced either from the melt or from fluxes. Since melt grown crystals must be cooled through several hundred degrees and often must undergo phase transitions, these crystals are generally highly strained. Flux grown crystals are also unsatisfactory because of the tendency to incorporate the flux into the lattice. In this paper a method of producing crystals with a transverse electro-optic effect at room temperature is presented which results in strain-free crystals of high purity. The principal material discussed is cuprous chloride which has the added advantage that it has transparency in the infrared range out to at least twenty microns. The system used for the evaluation of materials is discussed as well as as results for cuprous chloride and other materials produced by room temperature techniques. This work has provided a significantly improved laser modulator material of potential value for communication systems and similar applications.

10. Army Strategic Communications Command, Fort Huachuca, Ariz.
COMMUNICATIONS: INTRODUCTION TO SATELLITE COMMUNICATIONS. Supersedes AD-818 481. Distribution Limitation now removed. 15 Feb 1968, 335p.
USASCC-PAM-105-5. AD-830 471.

The purpose of the document is to introduce the fundamental techniques involved in satellite communications and to present some of the technology that personnel assigned to satellite communications ground stations must master if they are to become an efficient and effective work force. The pamphlet may be utilized as a supplementary text in the satellite communications training courses. Also, it may serve as an information type text for personnel not directly concerned with the satellite communications program, but who desire a general knowledge of the principles and techniques employed in the program.

11. Asmus, J. F.
LASER APPLICATIONS: A COMPARISON OF U.S. AND SOVIET TECHNOLOGY. Institute for Defense Analyses, Science and Technology Div., Arlington, Va. Rept. no. RP-P-586, Jun 1970, 121p.
Contract DAHC15-67-C-0011, Proj. ARPA-T-73.
IDA/HO 70-11034. AD-511 020. (SECRET)

In this study of the comparative technologies of the United States and the Soviet Union in laser applications, emphasis is placed on nine categories: biomedicine, chemistry, communication, computers and coherent optical data processing, environment, holography, materials processing, military, and plasma generation and heating. Information is drawn from scholars in the field and from written sources through the SECRET level. Among the study conclusions are the following: In most fields the lead or lag time is a year or less between the two. The U.S. effort can be characterized by early innovation of new laser types and proliferation of hardware. Soviet work emphasizes sustained R and D of particular early types. The USSR is slow to introduce new laser types into application even though there is a large body of theoretical Soviet literature on novel concepts. The field in which there is the greatest U.S./Soviet disparity appears to be holography; the United States is emphasizing it heavily, but there are few evidences of Soviet contributions. The Soviet Union is working extensively on the development of semiconductor laser computer logic elements, the United States very little (in part because of a commitment to electronic techniques).

12. Baker, T. L., J. H. Reid, and L. G. Van Pelt
LASER DESIGNATOR SEEKER SYSTEM (PAVE ARROW). Armament Development and Test Center, Eglin AFB, Fla. Final rept. 5 Jun 1968 – 30 Jan 1969. Report no. ADTC-TR-69-208. Oct 1969, 132p. AD-505 420. (CONF.)

13. Barnard, T. W. and C. R. Fencil
DIGITAL LASER RANGING AND TRACKING USING A COMPOUND AXIS SERVOMECHANISM. Applied Optics, Vol. 5, Apr 1966, pp. 497 – 505.

Description of a system for optical tracking which uses plane-polarized coherent laser beams and a compound-axis servosystem for providing a control of optical energy not previously available. This system gives precise tracking and slant-range information at a real-time sampling rate of 200 cps. The system utilizes a mirror assembly mounted on a tracking pedestal and provides angular data by tracking a laser-illuminated retroreflector mounted on the target. The slant range to the retroreflector is determined by a digital-mode FM CW-laser ranging system; the resolution and sampling rate of this system are under independent control.

14. Bayston, T. E. and D. A. Contini
LASER RECEIVER COUNTERMEASURES INVESTIGATION. Martin Marietta Corp., Orlando Div., Orlando, Fla. Interim technical rept. no. 1, 16 Mar – 21 Jun 1970. Rept. no. OR-10798, Jun 1970, 84p. Contract F33615-70-C-1555. AD-510 658L. (SECRET)

15. Bell Telephone Labs., Inc., Whippany, N. J.
DEEP SPACE COMMUNICATION AND NAVIGATION STUDY. VOLUME 1: SUMMARY. 1 May 1968, 45p. (Contract NAS5-10293). (NASA-CR-95571). N68-29521.

A comparison of alternative means for high data rate communication (about 10^6 b/s) from deep space probes, and the extent to which orbiting spacecraft can aid deep space navigation is provided. Emphasis is on the communication problem. A special

effort was made to delineate practical and theoretical constraints on communication from a distance of 1 to 10 AU at microwave, millimeter, and optical frequencies, and to indicate promising avenues for extending the art. The interrelationships between fundamental theory, device characteristics, and system performance has received particular attention in this study. Specific missions were synthesized, and problems of visibility. Doppler variation, handover, acqusition, tracking, and synchronization were investigated in order to discover the limitations imposed by practical system considerations.

16. Bell Telephone Labs., Inc., Whippany, N. J.
DEEP SPACE COMMUNICATION AND NAVIGATION STUDY. VOLUME 3: SYSTEM CONSIDERATIONS. Final Report. 1 May 1968, 142p. (Contract NAS5-10293(. (NASA-CR-95572). N68-29522.

A comparison of alternative means for high data rate communication (about 10^6 b/s) from deep space probes, and the extent to which orbiting spacecraft can aid deep space navigation is provided. Emphasis is on the communication problem. A special effort was made to delineate practical and theoretical constraints on communication from a distance of 1 to 10 AU at microwave, millimeter, and optical frequencies, and to indicate promising avenues for extending the art. The interrelationship between fundamental theory, device characteristics, and system performance has received particular attention in this study. Specific missions were synthesized, and problems of visibility. Doppler variation, handover, acquisition, tracking, and synchronization were investigated in order to discover the limitations imposed by practical system considerations.

17. Berbert, J. H.
INTERCOMPARISON OF GEOS-A OBSERVATION SYSTEMS. National Aeronautics and Space Administration, Goddard Space Flight Center, Greenbelt, Md. Jul 1967, 21p. (NASA-TM-X-55945; X-514-67-315). N67-39161.

The current status of NASA's Geodetic Satellite Observation Systems intercomparison investigation is presented. A number of accurate short orbital arcs (1/4 orbit) were determined with tracking data from the GEOS-A satellite tracking systems. Types of systems included were the NASA Goddard Range and Range Rate (GRARR), Laser and MOTS camera systems, the Army Sequential Collation of Range (SECOR) system, the Navy Tranet doppler system and the Air Force PC-1000 camera. Error model coefficients derived for the various systems include zero-set bias, timing bias, and refraction anomaly. These are determined to an accuracy better than the 10 meter goal of the investigation. Random noise estimates for these data were also determined. The Short Orbital arc technique of intercomparison is shown to give results consistent

with intercomparisons of data from collocated Laser and GRARR systems at Rosman, North Carolina.

18. Bivas, R.
THE FRENCH LASER TELEMETRY NETWORK (LE RESEAU FRANCAIS DE TELEMETRIE PAR LASER.)
COSPAR, Plenary Meeting, 10th, London, England, 24-29 Jul 1967, Paper. 13p. In French.

Application of laser techniques in the D1-C satellite program to a local spatial geodesy program for the purpose of studying, perfecting, and comparing new telemetry methods. The French observation network comprises three stations located in France, in Greece, and in the Sahara, equipped to measure the Doppler effect and to carry out laser telemetry. Experimental equipment, in addition to the satellite, consists of a Q-switched ruby laser and a receiver mounted in a tracking tower, coupled to an electronic chronometer and a recording clock. Suitable satellites for this method of trajectory plotting are the S-66, BE-C, GEOS, D1-C, and D1-D. Measurements made from these satellites are said to be of good accuracy. The quantity and quality of the measurements obtained indicates that the laser telemetry system is now operational.

19. Blackband, W. T.
PROPAGATION FACTORS IN SPACE COMMUNICATIONS. Advisory Group for Aeronautical Research and Development, Paris, France. Conference proceedings. Rept. no. AGARD-CP-3. 1967, 553p.
AD-674 170

Availability: Advisory Group for Aeronautical Research and Development, 7 Rue Ancelle, 92 Neuilly-Sur-Seine, Paris (France).

The Ionospheric Research Committee of the Avionics Panel of AGARD/NATO held its tenth annual symposium meeting in Rome 21-25 September 1965. The subject chosen for discussion was "Propagation factors in space communications." This volume presents the full text of those papers which have not been printed elsewhere and also an account of the informal discussions which followed the presentation of the papers.

20. Blanc-Lapierre, A.
INFORMATION THEORY AND ITS CONNECTIONS WITH PHYSICS AND ENGINEERING (La théorie de l'information et ses relations avec la physique et les sciences de l'ingénieur). Revue Générale de l'Electricite, vol. 79, Sep 1970, pp. 623-629. In French.

Review of the fundamentals, areas of application, and interdisciplinary affinities of information theory. Definitions of information and data processing are given, and such concepts as output of a data source and information handling-capacity of a channel are introduced. Causes of error are analyzed, and error-remedying action by coding is explained. The possibilities resulting from proper signal processing are illustrated by examples from space communication developments. Various topics including optical data-transmission channels, the effects of noise, the role of pass-bands, and the significance of holography are reviewed. The interdisciplinary connections of information theory with physics are discussed, and it is shown that acquired data in an information-processing system represents negative entropy.

21. Blattner, D. J., H. C. Johnson, and F. Sterzer
WIDEBAND MICROWAVE PHOTOTUBES FOR LASER COMMUNICATIONS SYSTEMS. IN RCA, Camden, N. J. Lasers (1963) pp. 27-28. (Contract DA 36-039-SC-90846). N64-12568.

The RCA developmental A-1283 microwave phototube is schematically diagramed, and its operation is described. The light to be modulated passes through the optical window onto a transmission type photocathode. The photoelectrons emitted by the cathode are bunched at the modulation frequency of the light. As these electrons pass through a traveling-wave-tube type helix, they excite a traveling wave that is taken out at the output coupler. The tube with its focusing periodic permanent magnets is 18 inches long and weighs 5 pounds.

22. Bogatov, G. B.
TELEVISION TRANSMISSIONS FROM SPACE (TELEVIZIONNYE PEREDACHI IZ KOSMOSA). Moscow, Izdatel'stvo Nauka, 1966, 304p. In Russian.

This book concerns television in its application to space missions, its role in the study of the earth, and the probable directions of future development. The use of TV

equipment in manned spaceflights and in proposed extraterrestrial observatories, based on artificial or natural celestial bodies, is explained. Attention is given to the problems of transmitting radio and TV signals over the distances encountered in space and the possibilities of employing EM oscillations in the optical range for communications purposes. Existing and planned facilities for repeating TV programs over intercontinental distances are discussed. The book is intended for a wide circle of readers.

23. Boyd, J. A. and R. H. Nelson
OPTICAL COMMUNICATIONS USING GALLIUM ARESENIDE INJECTICN LASERS. IN: Technology tc lay and tomorrow; Canaveral Council of Technical Societies, Space Congress, 7th, Cocoa Beach, Fla., April 22–24, 1970, Proceedings: Volume 1. Edited by T. H. Hanrahan, Cape Canaveral, Fla., Canaveral Council of Technical Societies, 1970, pp. 5-1 to 5-10, 6 refs.

A synthesis is presented which illustrates the applicability of gallium arsenide injection lasers as the source in high data rate optical communication systems. The synthesized system is a data link between two synchronous relay satellites separated by 45,500 statute miles. Requirements of the system were a data rate of 25 megabits per second and an information error rate of less than .00001. The system is synthesized using the parameters of commercially available injection lasers and photodetectors. A greater information capacity is shown when optimistic parameter values are used.

24. Brinkman, K. L., V. George, and J. Callis
DEEP SPACE OPTICAL COMMUNICATIONS SYSTEMS STUDY. Hughes Aircraft Co., Space Systems Div., Culver City, Calif. Final Report, 7 Nov 1962–15 Aug 1963, Aug 1963, 228p. (NASA-CR-56466; SSD-3473R). (Contract NAS9-879). N64-22447.

The following areas are discussed: (1) problems in the practical utilization of optical detectors in a laser communication system; (2) the characterization of the operating properties of numerous lasers (pulsed and CW, gas-liquid, solid-state, and semiconductor lasers with optical, electrical, and other types of pumping systems); (3) the statistical nature of the noise from the various lasers (i.e., coherence and stability properties); (4) various types of modulation systems that might be implemented; (5) various physical devices and their utilization in light modulation (estimates of the modulator power required, the percent of modulation and distortion, and systems

limitations are indicated); (6) various demodulation systems and a comparison between them, theoretically, for the purpose of establishing a performance characterization as a function of frequency, bandwidth, and external noise; (7) characterization of the information channel by presenting the effects of attenuation and external noise sources on system performance; (8) earlier interim reports concerning operations analysis with emphais on energy sources, tracking and pointing accuracy, and stabilization; (9) systems analysis and the establishment of the optimum operating frequency selection and the source-destination selection; and (10) the preliminary design of a PCM polarization modulation system.

25. Brinkman, K. L. and W. K. Pratt
DESIGN OF A LASER DEEP SPACE COMMUNICATION SYSTEM. Hughes Aircraft Co., Space Systems Div., El Segundo, Calif. (1963) 54p. N64-31014.

A survey of the state-of-the-art of laser optical detectors, modulation devices, and methods, is given, which establishes the basic properties of the transmitter and receiver system components. Modulation and demodulation systems are analyzed theoretically, and the channel is characterized in terms of the noise contributions from stellar, planetary, and atmospheric background, as well as noise contribution from the components themselves. A systems analysis procedure is developed to select the transmission frequency and the type of receiver. Based on the selection, a choice is made between direct communications from the DSV and communications via a microwave relay satellite. Next, a choice is made of the optimum modulation method for present day systems for the communication link selected. This is followed by a preliminary design analysis of the selected communication system. A comparison of that system with a present day microwave system for interplanetary communications is made.

26. Brock, E. G., T. S. Hartwick, and M. Silver
SATELLITE-TO-GROUND WIDEBAND COMMUNICATIONS STUDY. Aerospace Corp., Lab. Operations, El Segundo, Calif. Rept. no. TOR-0066(9990)-1, 3 Nov 1969, 82p. Contract F04701-69-C-0066. AD-865 278.

The report presents the results of an investigation into the potential of carrier frequencies above 10 GHz for satellite-to-ground relay. Emphasis was placed on systems that could deliver wideband information from satellites in low polar orbit to ground terminals within the continental United States and could be ready for space qualification by 1972–73. The short wavelengths of millimeter and laser frequencies are particularly attractive for narrow beam transmission from spaceborne transmitters because the required high gain antenna can be of a size that is easily accommodated

by contemporary satellites. Such narrow beams offer the desirable features of relative freedom from interception and interference and efficient use of the onboard radiated power. The advantages of the narrow beamwidths and large channel capacities that are inherently available from frequencies above 10 GHz must be weighed against increased demands for beam pointing accuracy and atmospheric propagation difficulties not enountered at lower frequencies.

27. Brockett, H. R.
OFFICE OF TRACKING AND DATA ACQUISITION MAINTAINS LIFELINES TO SPACE MISSIONS.
Aerospace Management, vol. 5, no. 1, 1970, pp. 93–100.

Discussion of the activities of the NASA Office of Tracking and Data Acquisition in providing mission support by maintaining lifelines between the ground and spacecraft over three specialized communications networks. The networks are specified as the Manned Space Flight Network supporting the Manned Flight Program, the Satellite Network supporting unmanned scientific and applications satellites, and the Deep Space Network supporting unmanned lunar and planetary missions. Basic information is given concerning the operations of these networks. Other functions of this Office include instrumentation support for aeronautical flight research programs conducted at the Langley Research Center and at the Flight Research Center at Edwards, the management of the NASA Communications System, and data processing at the Goddard Space Flight Center.

28. Brookner, E.
ATMOSPHERE PROPAGATION AND COMMUNICATION CHANNEL MODEL FOR LASER WAVELENGTHS.
IEEE Transactions on Communication Technology, vol. COM-18, Aug 1970, pp. 396–416, 133 refs.

Discussion of modeling the atmosphere communication channel at laser frequencies extending from the infrared CO2 laser wavelength of 10.6 micrometers to the visible laser optical wavelengths, such as the ruby wavelength of 0.69 micrometer. The diverse results given in the literature on electromagnetic propagation in the atmosphere are tied together for the purpose of giving a detailed specification of the pertinent characteristics of the atmosphere laser communication channel. Consideration is given to point and area receiver systems, heterodyne and direct detector receivers, nonplanar wave propagation. Clear weather conditions are assumed. Brief attention is also given to the channel additive noise.

29. Brookner, E., M. Kolker, and R. M. Wilmotte
DEEP-SPACE OPTICAL COMMUNICATIONS.
(NTC/66; Proceedings of the 1966 National Telemetering Conference, Boston, Mass., 10–12 May 1966, pp. 36–41.) IEEE Spectrum, vol. 4, Jan 1967, pp. 75–82. 8 refs.

Conference sponsored by the Institute of Electrical and Electronics Engineers, the Instrument Society of America, and the American Institute of Aeronautics and Astronautics. Bedford, Mass., Raytheon Co., 1966, pp. 36–41. 9 refs.

System design concepts are described which suggest the laser's promise to compete with rf in fulfilling wide-band (e.g., 10^7 bps), deep-space communication requirements. The advantages and problems in applying local heterodyne vs the proposed direct detection system (DDS) and transmitted reference system (TRS) with earth based large nondiffraction-limited optics and minimum size spacecraft optics are discussed.

30. Buckley, J.
GIANT APERTURE TELESCOPE STUDY. Perkin-Elmer Corp., Electro-Optical Group, Norwalk, Conn. 14 Dec 1966, 264p. (Contract NAS7-100; JPL-951288). (NASA-CR-81677; ER-8558). N67-17946.

Phase II results are presented of a design study to determine the optimum configuration and engineering guidelines for the ground receiver of a deep space optical communications system. A 120-in fully steerable telescope for coherent detection at a wavelength near 10 microns was studied. The telescope's astronomical ability was examined and found to be well suited for its primary role as a coherent optical deep space communications receiver as well as a general purpose astronomical telescope. The discussion provides details on selecting a mount configuration, acquisition and tracking, the mechanical design of the telescope and mount the optical system, the communications system tracking servo, system performance analyses, an error analysis, site location considerations, building and dome considerations, the telescope's astronomical utility, and an evaluation of a multiple aperture receiver.

31. Cessna, J. R.
BIT ERROR RATES AND TRANSIENT TIMES FOR A BINARY DIGITAL LOOP BIT SYNCHRONIZER IN ADDITIVE WHITE GAUSSIAN NOISE. Iowa Univ., Dept. of Physics and Astronomy, Iowa City, Iowa. Rept. no. U. of Iowa 70-49. Aug 1970, 40p. Contract N00014-68-A-0196-0003. AD-711 957.

A class of digital bit-synchronization phase-locked loops employing binary phase error quantization and sequential loop filtering is described. Two different types of data-derived phase detectors are assumed, one which depends on detection of the occurrence of data transitions and one which does not. Steady state and transient performance is analyzed in the presence of additive white Gaussian noise. This analysis is performed using a finite state periodic Markov model with unequal state duration times. Bit error rates and effective loop noise bandwidths are given.

32. Cetron, M. J.
NAVY TECHNOLOGICAL FORECAST, PART II. FUNCTIONAL AREA 200-COMMAND AND CONTROL, APPENDIX C. Deputy Chief of Naval Material for Development, Chief of Naval Development, Washington, D. C. 1 Oct 1969, 442p. AD-505 824L. (SECRET)

Updates report dated 1 Oct 1968, AD-392 618L.

33. Chapoton, C. W. and J. W. White
DEEP SPACE OPTICAL COMMUNICATIONS. American Institute of Aeronautics and Astronautics, Communications Satellite Systems Conference, Washington, D.C., 2-4 May 1966, Paper 66-317, 12p. Contract No. NAS 9-3650.

Communications requirements (for telemetry and real time television) are developed for a manned deep space mission and for an orbiting laboratory of the Apollo extended mission type. Communications systems are synthesized to satisfy these requirements using direct optical links for both missions; a relay link using microwaves to a synchronous satellite with optical wavelengths to the manned deep space vehicle are considered. PPM, PCM/PL, and coherent reception are considered for each link. These systems are analyzed and the best modulation technique chosen for each link. Parametric tradeoff curves and system parameters are presented showing PPM to have a power advantage on the uplinks and PCM/PL on the downlinks.

34. Chen, Fang-Shang
MODULATORS FOR OPTICAL COMMUNICATIONS.
Proceedings of the IEEE, Vol. 58, No. 10, Oct 1970, pp. 1440–1457.

This paper reviews the field of high-speed small-aperature modulators for applications in optical communications, with emphasis on electrooptic modulation. The capabilities and limitations of electrooptic modulators are discussed based on a review of the physical origin of the electrooptic effect. Thermal and photoconduction phenomena, which may severely limit the operation of practical devices, are emphasized. The modulation power and bandwidth limitations using various schemes of electrooptic interaction are derived and compared. It is shown that lumped modulators are capable of efficient modulation for bandwidths up to about 1 GHz for visible wavelengths and are also attractive for their simplicity. For broader bandwidth capability the traveling wave or zigzag types of interaction become more efficient but with added complexity. Finally, acoustooptic and mangetooptic modulators are briefly discussed and compared with electrooptic modulators.

34A. Chow, K. K. and W. B. Leonard
EFFICIENT OCTAVE-BANDWIDTH MICROWAVE LIGHT MODULATORS. IEEE Journal of Quantum Electronics, Vol. QE-6, No. 12, Dec 1970, pp. 789–793.

The use of wide-bandwidth interdigital microwave circuits to provide electrooptic modulation of light is discussed. Two models employing lithium niobate crystals of different aspect ratios have been constructed and tested. Both have nominal bandwidth from 1.0 to 2.0 GHz but actually give somewhat greater modulation bandwidth. Single-pass modulation tests made using 6328-Å light at RF drive power level of 5 watts show that 30 percent modulation depth over a 1.5-GHz frequency band is obtained for one model while approximately 50 percent modulation depth over a 1.1-GHz band is obtained for the other. These results show excellent agreement with analytical predictions. Measurement techniques are also discussed.

34B. Chow, K. K., R. L. Comstock, and W. B. Leonard
1.5-GHz BANDWIDTH LIGHT MODULATOR. IEEE
Journal of Quantum Electronics, Vol. QE-5,
Dec 1969, pp. 618–620.

A simple light modulator employing an interdigital microwave circuit and a short electrooptic crystal is described. Greater than 30 percent amplitude modulation, obtained by modulating the crystal birefringence, has been obtained between 0.8 and 2.3 GHz using 5 watts of RF drive power.

35. Chrysler Corp., Space Division, New Orleans, La.
OPTICAL TECHNOLOGY APOLLO EXTENSION SYSTEM. PHASE A, VOLUME 1. SECTION 1 AND 2: PROGRAM RESULTS AND OPTICAL TECHNOLOGY DEVELOPMENT PLAN. Final Technical Report. 18 Aug 1967, 80p. (Contract NAS8-20256). (NASA-CR-61924). N68-33481.

Future NASA space mission objectives were identified in order to asses the optical technology required and to outline a development program to provide this technology. Four major application areas are considered: astronomy, remote sensing, meteorology, and optical communications. Specific ground and space experiments are proposed and the relationship between these programs is examined. Also considered are alternatives for experiments, launch vehicles, spacecraft, spacecraft subsystems, and ground stystems. Thirteen experiments, designed to compare alternative design approaches to technology development, are recommended: heterodyne detection on earth and on the spacecraft, direct detection, communication with 10 megahertz bandwidth, precision tracking of a ground beacon, point ahead and space-to-ground-to-space loop closure, precision tracking from one ground station to another, 10 micron phase and amplitude correlation, pulse distortion measurements, primary mirror figure test and correction, thin mirror nesting principle, fine guidance, and comparison of isolation techniques.

36. Condon, R., D. Erway, and G. White
NASA-AMES LASER FIELD PROGRAMS. Electro-Optical Systems, Inc., Pasadena, Calif. IN: NASA, Marshall Space Flight Center Space Opt. Technol. Conf., vol. 2, Apr 1966, pp. 15–42. (Contract NAS2-2962). X68-18183.

NOTICE: Available to U.S. Government Agencies and Their Contractors Only.

Laser propagation and communication efforts are discussed with emphasis placed on studying the transmission characteristics of the total atmosphere from earth to space and return. The propagation experiments will involve transmission and attenuation measurements on laser beams from a ground tracking station to corner reflectors on the Explorer 22 satellite. The laser communication experiments will involve acquisition and tracking of a ground station 5145 Å argon laser beacon by Gemini 7 astronauts, with ground reception of laser communication from the spacecraft. Results of the Gemini 5 laser beacon experiment are appended.

37. Cooke, C. R. and A. R. Kraemer
OPTICAL COMMUNICATIONS IN SPACE. Fourth Conference on Laser Technology, San Diego, Calif. Jan 1970, p. 1339.

Analyzes various design parameters for laser space communications emphasizing acquisition and tracking and down-link communications through the atmosphere.

38. Cooley, James L.
ORBITAL TRACKING THROUGH SYNCHRONOUS SPACECRAFT. IN: Space sciences – Future applications for mankind; Vandenberg Scientific and Technical Societies Council, Western Space Congress, 1st, Santa Maria, Calif., 27–29 Oct 1970, Proceedings. Part 1. (A71-15276 04-31) North Hollywood, Calif., Western Periodicals Co., 1970, pp. 500–505, 5 refs.

An analysis is made of the orbit determination accuracy obtainable when a system of synchronous satellites is utilized for tracking near earth spacecraft. Three aspects of such a tracking situation are studied: (1) tracking synchronous satellites from ground stations, (2) tracking near earth phases of a manned mission through synchronous relay satellites, and (3) tracking near earth scientific satellites through synchronous

relay satellites. Such a system of synchronous satellites can meet both short-arc and long-arc tracking objectives. Application of tracking rhough synchronous relay satellites for advances in geopotential recovery is noted.

39. Defence Research Board, Ottawa (Ontario), Canada
REVIEW 1969 (REVUE 1969). Text in English and French. Rept. no. DRB-DR-204, 1969, 88p.
AD-868 205

This Review deals with activities during 1969 at the Defence Research Board's headquarters in Ottawa and its seven research establishments across Canada. The Review does not attempt to provide a full survey of the Board's operations and scientific projects, but instead concentrates on certain programs which have been selected to provide a general conspectus of the kinds of research with which the Board concerns itself.

40. DeLange, O. E.
WIDEBAND OPTICAL COMMUNICATION SYSTEMS: PART II – FREQUENCY-DIVISION MULTIPLEXING.
Proceedings of the IEEE, Vol. 58, No. 10, Oct 1970, pp. 1683–1690.

Frequency-division multiplexing techniques offer means for circumventing the bandwidth limitations of optical modulators and detector. Practical broad-band long-distance optical communication systems of this type appear feasible and some possible embodiments are described. Calculations are made to determine the approximate information capacity and other characteristics of several 4000-mile repeatered systems.

41. Denton, R. T.
THE LASER AND PCM. Bell Laboratories Record, Jun 1968, pp. 175–179.

These all refer to a HeNe pulse-locked system capable of 896 MBPS in four channels but actually demonstrated in two channels providing 448 MBPS. The 224 MBPS single channel demonstrated the transmission of two TV channels and 36 voice channels simultaneously. (One TV channel was reduced bandwidth.) Bell Laboratories recognized that about 10^8 BPS of binary information is needed per TV channel. The prediction of 10^{10} BPS by pulse-locked YAG laser and multiplexing was made.

42. Denton, R. T. and T. S. Kinsel
TERMINALS FOR A HIGH-SPEED OPTICAL PULSE CODE MODULATION COMMUNICATION SYSTEM: I. 224-Mbit/s SINGLE CHANNEL. Proceedings of the IEEE, Vol. 56, No. 2, Feb 1968, pp. 140–145.

The design of an experimental single-channel 224-Mbit/s (megabits per second) optical pulse code modulation terminal is described and data are presented which have been obtained with such a terminal using a helium-neon laser operating at 6328 Å. The basic element is an optical gate using lithium tantalate whose design and operating characteristics are described.

43. Diamond, P. M.
SATELLITE SYSTEMS FOR INTEGRATED COMMUNICATIONS, NAVIGATION, AND IDENTIFICATION. Aerospace Corp., Office for Development Planning, El Segundo, Calif. Rept. no. TR-0066(5521-01)-5 SAMSO-TR-70-160. 15 Feb 1970, 16p. Contract F04701-69-C-0066. AD-708 469.

Integrated communications, navigation, and identification (ICNI) implies two objectives: (a) implementation of a worldwide available command/control system, and (b) equipment and signal integration. Satellite systems can provide navigation capability and communications capability. Tactical satellite communications experiments have demonstrated feasibility; however, ICNI requirements dictate a wideband, high power, and large, expensive satellite. This satellite is developable during the latter 1970s. The navigation capability requires development and demonstration in the near future.

44. Dimeff, J., W. D. Gunter, Jr., and R. J. Hruby
SPECTRAL DEPENDENCE OF DEEP-SPACE COMMUNICATIONS CAPABILITY. IEEE Spectrum, Sep 1967, pp. 98–104.

A simple model of communications capability projected for the mid-1970s is formulated. The spectral dependence of the future state of the art is examined in terms of antennas, noise, diffraction effects, etc. The model suggests that the frequency spectrum in the vicinity of 10^{10} Hz would allow maximum information transfer and that radio-frequency techniques may be superior to the laser.

45. Dixon, T. P. and H. Dean Coombes and C. L. Wyman
A LASER GUIDANCE SYSTEM FOR RENDEZVOUS AND DOCKING. (Institute of Navigation, National Space Navigation Meeting, Boston, Mass., 21–22 Apr 1966, Paper.) Navigation, Vol. 13, Autumn 1966, pp. 231–245.

Development of a laser guidance system for rendezvous and docking which will provide the necessary intelligence to the guidance computer to effect a complete rendezvous and docking operation automatically. The system uses uncooled gallium arsenide laser arrays operating in a pulsed mode for initial acquisition and subsequent measurement of X and Y angles, angle rates, range, and range rates. When the distance between the two spacecraft has been reduced to less than 3 km, greatly increased range and range rate accuracy are obtained by the use of an incoherent gallium arsenide diode source continuously modulated at a high frequency, and using phase-locked detection techniques in the receiver. Control of the spacecraft from this sensor continues until the docking operation is completed.

46. Dore, M.
A LOW DRIVE-POWER LIGHT MODULATOR USING A READILY AVAILABLE MATERIAL ADP. Signals Research and Development Establishment, Christchurch (England). May 1968, 14p. (SRDE-68009) N69-18876.

A video-frequency transverse electrooptic light amplitude modulator utilizing the matrix element r_{41} in ADP is described and compared favorably with other modulator configurations using ADP, KDP, and KD*P. It utilizes two crystals to compensate for temperature and angular dependences of birefringence, and has more than adequate stability for normal laboratory use. A useful built-in optical bias control is provided. Frequency response has been measured between 50 Hz and 5 MHz and found to be flat. Video signals have been transmitted over a laser communication link using only 50-volt peak-to-peak dirve. Half-wave voltage is 220 volts and capacity is 53 pF, giving a drive-power requirement of 2.6 watts per MHz of bandwidth for 100-percent modulation depth, or 290 mW for 50-percent modulation depth. Optical transmission was 70 percent achieved by using an index matching liquid. An extinction ratio of 30:1 was obtained using a laser light source.

47. Doyle, W. M., W. D. Gerber, and P. M. Sutton
FM LASER COMMUNICATIONS THROUGH A HIGHLY TURBULENT ATMOSPHERE. IEEE Journal of Quantum Electronics, vol. QE-1, Jul 1965, pp. 181,182.

Experimental investigation of the effects of atmospheric turbulence on the operation of a dual-polarization FM laser communication system. The system uses an intracavity birefringent modulator to obtain two collinear output beams having mutually perpendicular polarizations and a controllable frequency separation. Heterodyne detection and rf limiting and discrimination are thus possible without an optical local oscillator. Field tests were conducted over a half-mile of hot pavement and open ground. Laboratory tests were carried out with a 3-ft long hot plate and a hot-air blower. Results indicate that, due to the dual-frequency nature of the transmitted signal, the phase modulation brought about by the atmospheric turbulence results in nearly pure amplitude noise, against which the circuitry of the FM receiver effectively discriminates.

48. Doyle, W. M., W. D. Gerber, and M. B. White
INVESTIGATION OF DUAL POLARIZATION LASER MODULATION. Philco-Ford Corp., Aeronutronic Div., Newport Beach, Calif. 25 Oct 1968, 92p. (Contract NAS9-7420). (NASA-CR-92484; U-4559). N69-16971.

This research program is aimed at determining the applicability of the dual polarization on laser to side band optical communication. A major part of this program has been devoted to a study of the bandwidth capabilities of a frequency modulated dual-polarization laser. Experiments were carried out with 1.15μ and 3.39μ He-Ne lasers, modulation frequencies of up to 20 MHz, and fm bandwidths of up to 130 MHz. The results indicate that the achievable bandwidths are considerably greater than would be anticipated on the basis of the static laser characteristics and that the limitations which do occur are of a type which would have a minimal effect on the operation of an fm communication system. Additional He-Ne experiments demonstrated the active frequency stabilization of the modulated DP laser and determined the effect of modulation on the stabilization characteristics.

49. Dressler, R. M. and E. C. Fraser
APPLICATION OF OPTIMAL LINEAR ESTIMATION AND CONTROL THEORY TO THE DESIGN OF OPTICAL TRACKING SYSTEMS. IN: University of Hawaii, Hawaii International Conference on System Sciences, 2nd, University of Hawaii, Honolulu, Hawaii, 22–24 Jan 1969, Proceedings. (A70-26301 11-10) Conference supported by the U.S. Air Force and the U.S. Navy. Edited by B. S. M. Granborg, North Hollywood, Calif., Western Periodicals Co., 1969, pp. 5–8. Contract No. NAS 12-59.

Description of the application of well known results in optimal linear estimation and control theory to the problem of high-precision tracking of a spacecraft by an optical telescope. For the system configuration studied, mathematical models of all system components were developed, including the relative motion of the spacecraft and the tracking telescope, the dynamics of the earth-terminal telescope, the optical propagation properties of the atmosphere and free space, and a statistical description of the optical and mechanical devices used to obtain control or output data from the system.

50. Dressler, R. M. and E. C. Fraser
AN ERROR DETECTOR FOR OPTICAL TRACKING CONTROL SYSTEMS. Stanford Research Institute, Menlo Park, Calif. IN: Hawaii International Conference on System Sciences, University of Hawaii, Honolulu, Hawaii, 29–31 Jan 1968, Proceedings. Conference sponsored by the University of Hawaii and the Institute of Electrical and Electronics Engineers, Edited by B. K. Kinariwala and F. F. Kuo, Honolulu, University of Hawaii Press, 1968, pp. 296–299.

Description of a tracking-error detection technique that yields extremely accurate angular measurements. One of the features of this measurement technique is that it can be implemented using presently available devices. The photodetector can be either a conventional image orthocon or a vidicon, both of which operate in a storage mode such that signal energy is integrated at each sample cell between readouts, thus

yielding maximum sensitivity. Since present data indicate that tracking-error detectors will not require signal bandwidths in excess of 100 Hz (Fraser and Dressler, 1966), a scan rate of only several hundred scans per second will be required. Generation of scans and reduction of data at this rate are well within the state of the computation equipment art.

51. Eden, D. D.
SO STATE TECHNIQUES FOR MODULATION AND DEMODULATION OF OPTICAL WAVES. Texas Instruments, Inc., Dallas, Tex. Quarterly rept. no. 3, 1 Nov 1962 – 31 Jan 1963, 31 Jan 1963, 44p. Contract DA36 039sc89221. AD-402 927.

A traveling wave quartz phase modulator was completed and is now being tested. Pure cuprous chloride crystals are still being grown for specific application in wide band TEM phase modulators. So far their size has been insufficient to be of practical application. An optical AM to FM converter using rutile has been completed and is undergoing tests. The mixing between axial modes from a helium neon gas phase optical maser at one Gcps was detected with a vacuum diode as well as a photomultiplier tube. Both mesa and planar diodes were constructed using an epitaxial N-type silicon having a normal substrate resistivity of 0.009 to 0.02 ohm-centimeters and a 13 ohm centimeter epitaxial layer. Total slice thickness was .007 in. and the layer was .0007 in. All photodiodes had sensitive areas of approximately 9×10 to the -4th power centimeters. Reverse breakdown voltage for the mesa detector is 15 microamperes at -120 volts. For the planar diode it is 10 microamperes at 45 volts. Relative spectral response was taken on both the mesa and planar photodiodes and is given in the text. Modulated light from the gallium arsenide diode was detected (using an air path) by a silicon epitaxial photodiode at approximately 400 megacycles per second.

52. Ffiedrich, H. R. and A. S. Halsted
ARGON LASER TO ACT AS BEACON SOURCE.
Hughes Research Lab., Malibu, Calif., Final Report, 15 Feb 1968, 11p. Contract NAS8-20806). (NASA-CR-61623). CSCL 20E. X68-13682.

NOTICE: Available to U.S. Government Agencies and Their Contractors Only.

The design and performance features of a compact, stable, long-life argon ion laser system which provides 1 W output at 4880 A in the TEM_{00} mode, are summarized. The system consists of a laser head, power, and heat exchanger. The components of the laser head consisting of the housing, mirror support structure, and discharge tube assembly, are described. The intensity of spontaneous emission lines from the argon

ion laser in the region from 2000 A to 8300 was measured. The strongest lines have intensities of 5×10^{-6} W and fall in the 3500 to 4300 A range. There are no lines in the spectral range from 6200 and 6600 A with intensities $>1 \times 10^{-7}$ W.

53. Fillmore, G. L. and G. Lachs
INFORMATION RATES FOR PHOTOCOUNT DETECTION SYSTEMS. IEEE Transactions on Information Theory, Vol. IT-15, No. 4, Jul 1969, pp. 465–468.

A model that allows one to calculate information rates for optical communication systems that use photocount detection is presented. This model has its basis in the coherent states of the field. It consists of a source that places the field in a coherent state, a channel that can introduce additive Gaussian noise, and a photodetector that produces the number of photocounts in the detection interval as output symbols. The capability of introducing additive Gaussian noise can also be used to represent a physical source.

The model is applied to several examples to illustrate its use. The rate of flow of information through the channel is calculated for a binary channel with and without additive Gaussian noise. The information rate for a noiseless channel is also obtained for the case in which the signals sent by a single-mode coherent source are selected from a Gaussian distribution.

54. Fletcher, P. C.
LASER BEACON STUDIES. Electro-Optical Systems, Inc., Pasadena, Calif., Final Summary Report, 30 Jun – 31 Oct 1961, 31 Oct 1961, 49p. (Contract NAS8-2439). (NASA-CR-62616; EOS-1920-Final). N65-23285.

A description is given of the various components of a laser beacon together with problems encountered. The weight of the beacon proper for an uncooled system, excluding components for synchronization, is estimated to be about 22 pounds, and the volume about 650-cu in.

55. Fried, D. L. and J. D. Cloud
ATMOSPHERIC TURBULENCE AND ITS EFFECT ON LASER COMMUNICATION SYSTEMS. SECOND REPORT. North American Aviation, Inc., Electro-Optical Lab., Los Angeles, Calif., IN: Its Exptl. Laser Space Commun. Program Task 1: Probl. Definitions, Vol. II, 9 Oct 1964, pp. 1–73. (TM-91). N64-32757.

A generalization is given of Rytov's methods for obtaining an approximate solution of the wave equation for a plane wave propagating through an inhomogeneous medium. This generalization is valid for any wave forms (such as spherical, elliptical, etc.), and from it Rytov's original result for plane waves can be derived as a special case.

56. Fried, D. L. and J. B. Seidman
HETERODYNE AND PHOTON-COUNTING RECEIVERS FOR OPTICAL COMMUNICATIONS. Applied Optics, Vol. 6, No. 2, Feb 1967, pp. 245–250.

The relative performance of an optical heterodyne receiver and a photon-counting receiver are compared. These conditions under which the two types of systems perform equally well are defined. Background noise is shown to be an almost negligible consideration. Detector noise is seen to be a much more severe problem. It is concluded that for wavelengths below 1μ, photon-counting reception is preferred because of the availability of photoemissive detectors. For wavelengths greater than 3μ, detector noise considerations are so severe that it is unlikely that photon counting will be competitive with heterodyne detection. The type of detection preferred in the $1-3\mu$ range is shown to be a matter of detector development.

57. Fried, D. L.
SCINTILLATION OF A GROUND-TO-SPACE LASER ILLUMINATOR. Optical Society of America, Journal, vol. 57, Aug 1967, pp. 980–983. 8 refs.

The problem of scintillation of a laser beam because of atmospheric turbulence, which has previously been studied for a horizontal propagation path, is studied in this paper for a path from a ground-based transmitter to a measurement point in space. The results are presented in terms of the log-amplitude variance $C_\ell(0)$, from which the intensity variance can be computed. The log-amplitude variance is found to be separable into a strength factor $Q_\ell^S(0)$ associated with the use of a zero-diameter source, and an aperture factor which measures the reduction of $C_\ell(0)$ caused by use of a large-aperture transmitter. Values of the aperture factor are calculated.

58. Gagliardi, R. M.
THE STUDY OF SYNCHRONIZATION TECHNIQUES FOR OPTICAL COMMUNICATION SYSTEMS.
University of Southern California, Electronic Sciences Lab., Los Angeles, Calif., Quarterly Report, 1 Dec 1968 – 1 Mar 1969, 1 Mar 1969, 14p. (Grant NGR-05-018-104). (NASA-CR-100898; QR-1). N69-25414.

The research effort is primarily analytical in nature and is divided into two categories. The first involves tasks with direct application to the synchronization problem, including that of optical communications systems in general: pure synchronization with direct detection, heterodyne detection, and pulsed lasers; impure synchronization with PPM systems; the effect of tracking errors on error rates in PPM systems; and synchronization as an estimation problem. The second category involves the following related areas also being studied; properties of shot noise processes, optimal optical detection and filtering, and the information capacity of Poisson (optical) channels.

59. Gagliardi, R. M. and S. Karp
M-ARY POISSON DETECTION AND OPTICAL COMMUNICATIONS. IEEE Transactions on Communication Technology, Vol. COM-17, No. 2, Apr 1969, pp. 208–216.

This paper presents an investigation of the problem of maximum likelihood detection of one of M Poisson processes in a background of additive Poisson noise. When the observables correspond to counts of emitted photoelectrons, the problem models a discrete version of a coherent M-ary optical communication system using photon counters in the presence of background radiation. Consideration is given to an average distance and a detection probability criterion. The advantages of an M-ary pulsed intensity set (Poisson intensities wholly concentrated in a single counting interval) are demonstrated. The performance of such intensity sets is exhibited in terms of error probabilities, pulse widths, signal-to-noise ratio, and channel capacity. Behavior as a function of number M of intensities is also discussed. By appropriate conversion these results may be used for determining power requirements in an optical pulse position modulation system.

60. Gallager, R. G.
RESEARCH ON TECHNIQUES OF COMMUNICATION IN THE SPACE ENVIRONMENT. Massachusetts Inst. of Tech., Electronics Research Lab., Cambridge, Mass. Semiannual Status Report, 1 May – 31 Oct 1968, 19 Nov 1968, 7p. (Grant NGL-22-009-013). (NASA-CR-98518). N69-13245.

Research is summarized which is aimed toward understanding of communication channels and sources for the development of reliable, efficient communication techniques. Progress is reported in two studies, the first of which is in optical communication and deals with the fundamental limitations and efficient utilization of optical channels, including the turbulent atmospheric channel, the cloud transmission channel, quantum-limited channels, and scatter channels. The studies range from channel modeling through feasible near-optimum communication systems to fundamental coding theorems. The second study is concerned with coding for noisy channels and for sources. Briefly described is work on systematic convolutional codes, their sequential decoding, and the transmission of a discrete-time Gaussian source over an additive white Gaussian noise channel with a mean square error criterion.

61. Gambling, W. A. and P. J. R. Laybourn
COMMUNICATING WITH LIGHT. Science Journal, Vol. 5A, Dec 1969, pp. 40–46. 6 refs.

Discussion of the capabilities of a communication system using laser light beams. Three distinct directions of development of optical communications are examined: (1) communication systems for outer space, where diffraction and aiming with the required degree of accuracy are the only limiting factors; (2) beam guiding systems offering a huge bandwdith; and (3) fiber optical guides for more modest bandwidth.

62. Gammarino, R. R., E. J. Schiel, and E. Aras
DESIGN AND PERFORMANCE OF AN INJECTION LASER LINK FOR HIGH (10 MHz) DATA RATE TRANSMISSION. IN: Electro-Optical Systems Design Conference, 1st, New York, N. Y. 16-18 Sep 1969, Proceedings. Edited by K. A. Kopetzky, 1970, pp. 120-127, 6 refs. Contract No. DA-28-043-AMC-01272(E).

Discussion of the operational characteristics of an experimental injection laser communication link and of the design and construction of the transmitter and receiver used in the experiment. The link was set up over a 13 km range. The characteristics of the injection laser are discussed and the injection laser driving circuit is described. Aspects of transmitter optics are examined and details regarding the reception and attenuation of the signal are considered taking into account effects created by normal atmospheric turbulence.

63. Gammarino, R. R. et al.
HIGH DATA RATE INJECTION LASER COMMUNICATIONS LINK. U.S. Army Electronics Command. Report ECOM-2912, Dec 1967.

Demonstrated 10 MBPS with considerable excess signal to tolerate large weather losses and to operate at 10 km distance. GaAs laser operated at 77°K.

64. General Electric Company, Valley Forge Space Technology Center, Philadelphia, Pa.
OPTICAL SPACE COMMUNICATIONS SYSTEM STUDY. VOLUME III: SYSTEM TOPICS - PART TWO. Final Report, 7 Feb 1964, 123p. (NASA Contract NASw-540). (NASA CR-53466). N64-18133.

The following are discussed with respect to optical space-communications systems: (1) photomultiplier detectors - performance of photomultiplier detectors on signals that are close to the noise level of the detector; (2) effect of atmospheric turbulence on laser propagation - absorptive attenuation, scattering (nonabsorptive attenuation), "seeing" effects caused by random fluctuation in the index of refraction of the air, and potential high-energy effects; and (3) laser optics - transmitting optics, receiving optics, filtering, and detection of faint sources.

65. General Electric Company, Valley Forge Space Technology Center, Philadelphia, Pa. OPTICAL SPACE COMMUNICATIONS SYSTEM STUDY. VOLUME II: SYSTEM TOPICS – PART ONE. Final Report, 7 Feb 1964, 97p. (NASA Contract NASw-540). (NASA Cr-53467). N64-18132.

Results are presented of tests on star observations, on photomultiplier performance, and on the effects of the atmosphere on laser propagation. The study supported the belief that optical communication has the potential to replace radio and to perform unique functions in many space situations. Certain methods are proposed to overcome the restriction of receivers to small-area-collecting optics in the atmosphere and to high-quality optics in any case.

66. Geusic, J. E., W. B. Bridges, and J. I. Pankove COHERENT OPTICAL SOURCES FOR COMMUNICATIONS. Proceedings of the IEEE, Vol. 58, No. 10, Oct 1970, pp. 1419–1439.

The development of coherent optical sources, producing usable amounts of power, has provided a stimulus for communications research. Coherent sources in the form of lasers and parametric oscillators are available at wavelengths which span the entire optical spectrum. This paper reviews the state of the art of coherent optical sources with major emphasis on the most highly developed sources.

67. Glaser, W. A FEW CONSIDERATIONS CONCERNING THE APPLICATION OF FREE-SPACE COMMUNICATION SYSTEMS IN THE LIGHT-WAVE REGION (EINIGE BETRACHTUNGEN ZUR ANWENDUNG VON FREIRAUM-NACHRICHTENSYSTEMEN IN LICHTWELLEN-BEREICH). Air Force Systems Command, Foreign Technology Div., Wright-Patterson AFB, Ohio. (Transl into English from Nachrichtentechnik (E. Germany), v. 15, no. 9, 1965, pp. 340–343. (FTD-HT-67-297: AD-838115). X68-20379.

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The general relations characterizing the free-space communications systems were discussed and communication systems based on ultrahigh frequency and light-wave region were compared. The comparative parameters of the two systems were evaluated and it was concluded that the principal system-theoretical advantage of the light-wave region system is the availability of highly collimated bundles of rays.

68. Goldhammer, J., J. Schwartz, and J. McClelland
RELAY-SATELLITE/SPACECRAFT SYSTEMS.
Institute for Defense Analyses, Science and Technology Div., Arlington, Va. Rept. no. RP-P-421, Jun 1969, 54p. Contract DAHC15-67-C-0011, IDA/HQ 68-9101 AD-504 132. (SECRET)

69. Goodwin, F. E. and T. A. Nussmeier
OPTICAL HETERODYNE COMMUNICATIONS EXPERIMENTS AT 10.6 μ. IEEE Journal of Quantum Electronics, Vol. QE-4, No. 10, Oct 1968.

A 10.6-μ optical heterodyne communication system that is in operation over a 30-km (18-mile) path is described. Television signals have been transmitted over the beam by the use of optical FM achieved with internal electrooptic phase modulation of the transmitter oscillator. A frequency deviation of 3 MHz is thus obtained for a driving voltage of 1 kV compared with the fundamental frequency noise of the system of about 1 kHz. For clear-day operation, average carrier-to-noise ratios at the receiver approach 60 dB, and demodulated video signal-to-noise ratios average 50 dB.

Optical propagation experiments reveal amplitude scintillation noise in excess of 20 dB, represented by fluctuations of +10 dB and -10 dB from the average carrier level. Other observations show that the 10.6-μ beam has a remarkable ability to penetrate fog. Data related to scintillation, visibility, temperature, humidity, and optical absorption are presented.

70. Goodwin, F. E.
A REVIEW OF OPERATIONAL LASER COMMUNICATION SYSTEMS. Proceedings of the IEEE, Vol. 58, No. 10, Oct 1970, pp. 1746–1752.

Laser communication systems which have been built into serviceable units are reviewed. Although systems built prior to 1965 were more of a breadboard nature, some early experiments of historical interest are described. After 1965, techniques and component reliability were sufficiently improved to permit the development of several interesting and sophisticated systems. Performance characteristics of the more representative of thse systems are listed. Recent trends show the use of infrared wavelengths, injection lasers, mode-locked/pulse-code modulation systems, optical heterodyne detection, and automatic pointing and tracking.

71. Goss, Q. J.
LASER COMMUNICATIONS IN SPACE. Fourth Conference on Laser Technology, San Diego, Calif., Jan 1970, p. 1329.

Discusses expectations for military laser satellite communication.

72. Gray, L. A.
DATA COMPRESSION. Naval Postgraduate School, Monterey, Calif. Master's thesis, Jun 1969, 95p.

A study of data compression techniques involving linear interpolation and linear prediction showed that redundancy is a problem that can be significantly reduced by various polynomial approximations. A more recent compressor, the continuous secant compressor which determines the optimum sampling interval prior to sampling, was found to be the most efficient compressor examined. The continuous secant compressor bases its reduction technique on a straight-line approximation. Data compression results when the system in question does not occupy its entire bandwidth. The addition of white noise over the entire bandwidth was found to reduce the efficiency of the continuous secant compressor by only a small amount. The probability distribution of the straight-line approximation in the presence of noise had a gaussian distribution and a relatively small standard deviation.

73. Green, D., W. A. Yates, and S. P. Lazzara
AIRBORNE APPLICATIONS STUDY. VOLUME V. APPENDICES. Hughes Aircraft Co., Aerospace Systems Div., Culver City, Calif. Final rept. 3 Apr – 29 Sep 1969, Oct 1969, 177p. Contract F29601-69-C-0099. AFWL TR-69-125-Vol. 5. AD-510 854. (SECRET)

Volume 5 contains 14 independent appendices, including calculations, derivations, analyses, subsystem performance studies, and related technology discussions. The data contained in these appendices substantiate many of the values cited in Volume I through IV of the Airborne Applications Study report, and are separately bound to enhance the accessibility of the data.

74. Gundersdorf, C. J. and J. M. Minkowski
QUANTUM LIMITATIONS ON OPTICAL COMMUNICATIONS. Johns Hopkins University, Carlyle Barton Lab., Baltimore, Md. Final rept. 1 Dec 1966 – 31 Jan 1968, Feb 1969, 88p. Contract F33615-67-C-1169, AFAL TR-68-375. AD-857 992

75. Halme, S. J.
EFFICIENT OPTICAL COMMUNICATION IN A TURBULENT ATMOSPHERE. Massachusetts Inst., of Tech., Research Lab. of Electronics, Cambridge, Mass. 1 Apr 1970, 122p. (Grant NGL-22-009-013; DA-28-043-AMC-02536(E). (NASA-CR-109889; TR-474). N70-28201.

Given a transmitter that radiates an electromagnetic light field, it is assumed that the resulting field at the plane of the receiver aperture is log-normal with some coherence properties. Various representations of the field are discussed; aperture sampling, plane-wave decomposition, and Karhunen-Loeve expansion. The statistical properties of the coefficients in these representations are investigated by analytical, simulation, and experimental methods. Based on these representations the problem of optimum detection of an orthogonal signal set, subject to distortion and noise in the atmosphere, is investigated. The optimum receiver and its performance are evaluated

and discussed in the cases of log-normal and Gaussian statistics, classical and quantum models, large and small apertures, and strong, weak or absent background noise.

76. Hance, H. V., R. C. Ohlmann, D. G. Peterson, R. B. Ward, and K. K. Chow
ULTRA-WIDE BANDWIDTH LASER COMMUNICATIONS: PART II – AN OPERATING LABORATORY SYSTEM. Proceedings of the IEEE, Vol. 58, No. 10, Oct 1970, pp. 1712–1719.

A description is presented of the system configuration, principal components, and preliminary system test results of a laboratory laser communication link for high-fidelity transmission of baseband analog signals with bandwidths up to 0.4 GHz. An experimental system is described in which the information signal first is frequency modulated onto a 1.5-GHz microwave subcarrier. This FM subcarrier is then intensity modulated onto the laser beam by means of a gigahertz-bandwidth electrooptic modulator. The FM/IM signal on the beam is demodulated in the optical receiver by means of a fast-response photodetector and a gigahertz-bandwidth frequency discriminator. Results of initial measurements of linearity and frequency-response characteristics of the signal-handling components of the system are given, as well as overall system characteristics. A single-frequency argon laser is used as the source of the optical carrier.

77. Hannan, W. J. D. Sarnoff, and J. Bordogna
COMPARISON OF ELECTROOPTIC MODULATION METHODS. IEEE Transactions on Aerospace and Electronic Systems, vol. AES-4, Nov 1968, pp. 874–878, 6 refs.

A comparison is made among normal AM, wide-band analog FM, and PCM as applied to transmission of real-time TV pictures via an electrooptic space communication system. The comparison is based on the requirement to receive a subjectively noise-free TV picture. Based on the results of this comparison, it is concluded that analog-FM subcarrier modulation is the best practical choice for transmission of real-time TV pictures in space via a laser beam. In addition to providing performance equivalent to that of coherent, PCM, this type of modulation can be implemented with comparatively simple equipment.

78. Hannan, W. J. et al.
ELECTRO-OPTIC TV COMMUNICATIONS SYSTEM. IEEE Proceedings, Feb 1965, pp. 171–172.

Operation of an optical TV communications system employing a gallium arsenide (GaAs) electro-optic crystal was successfully demonstrated using the configuration shown in Fig. 1. In this system the polarizer permits only light polarized in one plane to reach the crystal. As the plane-polarized light passes through the crystal, it becomes elliptically polarized, the ellipticity depending on the voltage applied to the crystal. Since the analyzer transmits light polarized in only one plane, the intensity of the light transmitted through the modulator depends on the amount of rotation of polarization introduced by the crystal. Hence, the light beam is amplitude modulated in accordance with the voltage applied to the crystal.

79. Harger, R. O.
MAXIMUM LIKELIHOOD AND OPTIMIZED COHERENT HETERODYNE RECEIVERS FOR STRONGLY SCATTERED GAUSSIAN FIELDS. Optica Acta, vol. 16, Nov–Dec 1969, pp. 745–760, 19 refs. Contract No. AF33(615)-3100.

The maximum likelihood receiver (MLR) to detect a pulsed signal propagated through a turbulent medium is found under assumptions that approximate optical propagation over a long path through the atmosphere. Limiting cases of the MLR are the coherent heterodyne receiver (CHR) and the total-energy-measuring receiver. With an additional assumption, the probability of error of the MLR is approximated. The CHR, even with an optimally chosen aperture weighting function, can be markedly inferior to the MLR. Unlike the optimized CHR, the MLR can effectively use arbitrarily large apertures. A coherent optical system is given that, in principle, realizes the MLR.

80. Harned, B.
MODULATION INDUCING RETRODIRECTIVE OPTICAL SYSTEM. Philco Corp., Research Labs., Blue Bell, Pa. Technical Report 21 May 1963 – 20 May 1964, Sep 1964, 70p. (Contract NASw-721). (NASA-CR-67461). N65-19864.

An investigation was conducted of the feasibility of an optical communications network making use of a passive modulation inducing device. The concept of MIROS, a Modulation Inducing Retrodirective Optical System, considers a passive element whose

reflectivity changes in accordance with light of different frequencies and intensities so that the modulation of one beam is transferred within the element to another beam. Studies indicated that this system is feasible for long-distance communication, using laser sources, and also that a number of techniques are possible. A rate equation analysis of a simple three-level scheme in a two-photon absorption process shows that the frequency response for cross modulation eventually falls off as ω^{-1}, but that the onset of this falloff may be shifted in frequency with the proper choice of the two beam intensities in comparison with the system relaxation time. Experimental investigations were concerned primarily with the production of amplitude modulation effects in optical pumping of cesium vapor, but the possibility of using the Franz-Keldysh absorption band edge shift in semiconductor materials with optical pumping were developed, spanning the electromagnetic spectrum from audio to optical frequencies.

81. Helbig, H. S. and F. Malota
SATELLITE POSITION FINDING WITH LASERS (SATELLITENORTUNG MIT LASER). Raumfahrtforschung, Vol. 13, Sep–Oct 1969, pp. 228–235, 28 refs. In German.

Discussion of the application of the laser technique to satellite position finding and orbital surveys. In using the laser technique, suitable satellites are fitted with corner reflectors which reflect the light received to the ground station. A review is made of current applications of the laser technique in satellite position finding. A detailed description is given of two types of laser transmitters used in satellite position finding. It is shown that improvements in laser transmitters make it possible to perform measurements of other satellites. It is also shown that laser measurements can be considerably invalidated or can even fail completely through the influence of the atmosphere; several factors in this connection, such as refraction, deflection due to air turbulence, and light attenuation due to absorption and diffusion are discussed in detail. Applications of satellites fitted with corner reflectors are reviewed, including the use of such satellites in geodetic global triangulation and in determinations of the earth's gravitational field, and some future development possibilities are outlined.

82. Helstrom, C. W., J. W. S. Liu, and J. P. Gordon
QUANTUM-MECHANICAL COMMUNICATION THEORY. Proceedings of the IEEE, Vol. 58, No. 10, Oct 1970, pp. 1578–1598.

This paper is concerned with the problem of finding the structure and performance of the receiver that yields the best performance in the reception of signals that are described quantum-mechanically. The principles of statistical detection and estimation theory are discussed, with the laws of quantum mechanics taken into account. Several specific communication systems of practical interest are studied as examples of applying these principles. Basic concepts in quantum mechanics that are needed in these discussions are briefly reviewed.

83. Henry, H. E.
DEFINITION OF OPTICAL ATMOSPHERIC EFFECTS ON LASER PROPAGATION, VOLUME III. North American Aviation, Inc., Space and Information Systems Div., Downey, Calif. 4 Aug 1965, 104p. (Contract NAS w-977) (NASA-CR-67382; SID-65-1084, Vol. III). N65-35846.

An extended review of types of measurements and limitations of atmospheric effects on optical propagation is given. A brief analysis of cloud transmittance indicated that for relatively thin clouds the major part of the transmitted signal is coherent while for thick clouds the majority of the transmitted light is scattered. The applicability of analytical work on wave propagation through a random media to the prediction of the time-power spectrum of the amplitude and phase fluctuations of a propagating wave is discussed, and recommendations for additional analyses are indicated. It was concluded that ray optic methods could be used to provide a good approximation to phase problems, but not to amplitude problems. A method of acquiring and categorizing data related to the laser space communications study is also presented.

84. Hertel, R. and I. Lowen
SCANNING CELESTIAL ATTITUDE DETERMINATION SYSTEM FOR A STABILIZED SATELLITE. IN: Electro-Optical Systems Design Conference, 1st, New York, N. Y., 16–18 Sep 1969, Proceedings. Edited by K. A. Kopetzky, Chicago, Industrial and Scientific Conference Management, Inc., 1970, pp. 387 –394. Contract No. NAS 5-10492.

Discussion of the design features of the Scanning Celestial Attitude Determination System (SCADS) being developed to provide a simple means for determining triaxial attitude information for earth-stabilized satellites with an accuracy of 0.1 deg rms or better. This system scans a portion of the sky with a rotating slit and compares the measured angular separations between the stars with a star catalog stored in a ground-based digital computer. Changes in the satellite attitude are reflected by changes in the measured angles between stars. The computer uses an iterative procedure to find the attitude which gives the best fit to the observed angles.

85. Hirano, J., Y. Hoshiko, and C. Okawara
AN OPTICAL PULSE-COMMUNICATION SYSTEM.
IEEE Journal of Quantum Electronics, Jun 1969,
p. 350.

High-speed optical pulses from mode-locked lasers and a high efficiency modulation by oxide ferroelectric crystals have enabled us to transmit wide-band signals by optical pulse modulation. In this paper, an experimental system of laser communication in delta modulation and pulse code modulation is described, together with its operational characteristics.

86. Hodara, H.
LASER WAVE PROPAGATION THROUGH THE ATMOSPHERE. IN: Propagation Factors in Space Communications; AGARD/NATO Avionics Panel, Ionospheric Research Committee, Annual Symposium, 10th, Rome, Italy, 21-25 Sep 1965, Papers. Edited by W. T. Blackband. Maidenhead, England, Technivision (AGARD Conference Proceedings No. 3), 1967, pp. 445-474, 24 refs.

Discussion of the nature of random thermal turbulences which degrade the high directionality and coherence of laser light and produce random deflection of the laser beam in laser communications. The deflection may be severe enough to make the beam miss the receiving aperture, while the coherence degradation leads to beam broadening. In both instances, the result is a reduction of the useful signal intensity at the receiver coupled with undesirable amplitude and frequency modulation and polarization fluctuations. Another limitation imposed on direct optical display transmission is "quivering" or spot dancing caused by random beam deflection and blurring of the received image due to spatial coherence degradation. Some experimentally determined effects of thermal turbulence on laser propagation are noted.

87. Hoff, F. et al.
CZECHOSLOVAK STUDY OF INFORMATION TRANSMISSION OVER AN OPTICAL COMMUNICATION SYSTEM WITH AN He-NE LASER. Joint Publications Research Service, Washington, D.C. 24 Apr 1968, 18p. Transl. into English from Elektrotech. Casopis (Czech)., No. 1, Feb 1968, pp. 3-19. (GUO: 2766).

NOTICE: Available to U.S. Government Agencies Only.

A description and the results are presented of experiments to transmit narrow-band information over an optical communication system employing an He-Ne laser. The problems of the laser beam's modulation, propagation, and detection are analyzed in detail. Attention is devoted also to the effect of atmospheric turbulence on transmission quality when using an AM laser beam.

88. Hopkins, R. H., N. T. Melamed, and T. H. Henningsen
RARE EARTH DOPED APATITIE LASER MATERIALS. Westinghouse Research Labs., Pittsburgh, Pa. Semi-annual rept. no. 2, 20 Mar-19 Sep 1970. Rept. no. 70-6J8-REDAP-R2, Dec 1970, 113p. Contract F33615-70-C-1051, ARPA Order-1467. AFAL TR-70-249. AD-878 030.

The report describes the current status of the second and third phases of a program to evaluate certain members of the apatite mineral family as hosts for the active laser ion holmium. A systematic study of the effect of growth parameters in the quality of fluorapatite (FAP) crystals doped with holmium and chromium indicates that growth rates below 2 mm/hr and rotation rate of 80 rpm should be optimum for crystal growth. For these conditions the distribution coefficients of Ho and Cr in FAP are 0.34 and 0.24, respectively. The physical properties of CaYSOAP have been measured and compiled. These properties were also tabulated for FAP. CaYSOAP exhibits a laser threshold of 30 to 60 joules at 77°K. Despite approximately 10%/cm scattering losses efficiencies of 0.61% have been obtained in long pulse tests from these crystals. An unsaturated Q-switch output of 50 mj with 135 j input to the lamp has been achieved for CaYSOAP.

89. Hoversten, E. V., R. O. Harger, and S. J. Halme
COMMUNICATION THEORY FOR THE TURBULENT ATMOSPHERE. Proceedings of the IEEE, Vol. 58, No. 10, Oct 1970, pp. 1626–1650.

This paper is concerned with an examination of how statistical communication theory can be used to combat the effects of atmospheric turbulence in optical communication systems. The objective is to provide a framework to be used in discussing and relating the analytical results presently available in the literature as well as some new, or at least not widely known, results and in motivating and guiding future work.

Both digital communication and parameter and waveform estimation are considered, with the greater emphasis on the former. As necessary mathematical preliminaries, the relevant statistical channel model, the problems of spatial representation, quantum field models, and the output statistics of optical detectors are considered. For digital-communication systems, the structure and performance of optimum quantum receivers and of structured receivers, e.g., direct and heterodyne-detection receivers with either a single detector or a detector array, are discussed and related. The simplifying approximations and assumptions required to obtain these results are emphasized. Estimation theory is considered primarily from a classical (nonquantum) viewpoint. The quadratic functional structure of the processors are emphasized. Cramer-Rao bounds on the estimation performance are considered and applied to several examples.

90. Hughes Aircraft Co., Aerospace Group, Culver City, Calif.
PARAMETRIC ANALYSIS OF MICROWAVE AND LASER SYSTEMS FOR COMMUNICATION AND TRACKING. Quarterly Report, 6 Aug–6 Nov 1965. 30 Nov 1965, 129p. (Contract NAS5-9637). (NASA-CR-74989; P65-149; QR-1). N67-32164.

This report describes the work performed during this period on a parametric analysis of microwave and laser communication and tracking systems. Information and conclusions of previous studies were acquired and critiqued. The critiques list the significant contributions of each study and the location of the material within the body of the report. The critiquing has been completed for telecommunications and is in progress for the acquisition and tracking portion. Progress is reported on the three sections of a space design handbook. These sections include a methodology for solving space communication and tracking problems, parametric studies of the parameters involved in the methodology, and a state-of-the-art documentation of the parameters values.

91. Hughes Aircraft Co., Aerospace Group, Culver City, Calif.
PARAMETRIC ANALYSIS OF MICROWAVE AND LASER SYSTEMS FOR COMMUNICATION AND TRACKING. Quarterly Report 6 Mar – 6 Jun 1966. Jun 1966, 387p. (Contract NAS5-9637). (NASA-CR-77943; P66-135; QR-3). N67-32165.

Five technical sections of the first issues of reference data for advanced space communications and tracking systems are updated. The sections include mission analysis, transmitting power sources, optical modulators, acquisition and tracking, and background radiation and atmospheric attenuation. Manned and unmanned space missions envisioned over the next several decades are summarized. The primary objectives of each mission are described and implied communication requirements are discussed. The transmitting power sources section is enlarged in the area of solid state power sources in the microwave region and in the area of CO_2 laser technology in the optical region. Acquisition and tracking efforts were directed towards documentation of the basic constraints within which an acquisition and tracking system must operate and an examination of the constraint effects on some general configurations. Some of the more important advances in optical modulation which are currently in progress are discussed and a section on elasto-optic modulation has been added. Current information concerning external noise sources relevant to optical and microwave space communication systems is presented.

92. Hughes Aircraft Co., Aerospace Group, Culver City, Calif.
PARAMETRIC ANALYSIS OF MICROWAVE AND LASER SYSTEMS FOR COMMUNICATION AND TRACKING. Quarterly Report 6 Jun – 6 Sep 1966. 6 Sep 1966, 410p. (Contract NAS5-9637) (NASA CR-82101; P66-213; QR-4). N67-32166.

Reference data for advanced communications and tracking systems are presented to provide a methodology for solving space communication and tracking problems, parametric studies of the parameters involved in the methodology, and a state-of-the-art documentation of the parameter values. In addition, an evaluation is made of the capability and amenability to modification of the available communication and tracking systems to the increased performance requirements of future microwave and optical communications systems. The presentation covers communication theory along with an analysis of the modulation, detection, and coding processes of communication systems; the performance and theory of radio frequency and optical detectors; acquisition and

tracking with emphasis on a narrow beamwidth optical problem; radio frequency antennas for space and earth based applications; and key parameters and systems concepts of previous communications systems designs for comparison purposes.

93. Hughes Aircraft Co., Aerospace Group, Culver City, Calif.
ADVANCED DEEP SPACE COMMUNICATION SYSTEMS STUDY. Final Report, Jan 1967, 307p. (Contract NAS12-81) (NASA-CR-82879; P67-15). N67-20164.

Results are presented of a study to define areas of technology where research effort can best be expended in order to meet deep space communication needs in the period 1970 to 1980. The communication system requirements are discussed for deep space missions with reference to transmission range, data rate, and angular coverage. Basic limitations to system performance are reviewed and include minimum signal requirements, noise sources and their spectral characteristics, and atmospheric attenuation and distortion effects. Practical limitations on performance due to the present and projected state of technology are discussed with reference to radio frequency and optical components. Based on the various performance limitations expected communication link performance is analyzed as a function of frequency to determine suitable frequencies and system configurations. A review of the present state of the art in radio frequency and optical technology a discussion of potential developments, and an indication of promising areas for research are included.

94. Hughes Aircraft Co., Aerospace Group, Culver City, Calif.
REFERENCE DATA FOR ADVANCED SPACE COMMUNICATIONS AND TRACKING SYSTEMS. 6 Feb 1966, 526p. (Contract NAS5-9637) (NASA-CR-86910; P66-16). N67-32322.

Overall systems trade-off studies were conducted in sufficient detail to identify missions which will make the best use of laser/optical, microwave, or a combination of microwave and laser/optical communication and tracking systems. A plan is presented for optimumly integrating such systems into present and future world-wide systems. Systems design criteria and specifications are provided, along with the methodology which provides a basis for determining the optimum system configuration.

95. Hughes Aircraft Co., Aerospace Group, Culver City, Calif.
PARAMETRIC ANALYSIS OF MICROWAVE AND LASER SYSTEMS FOR COMMUNICATION AND TRACKING. First Quarterly Report, 6 Aug – 6 Nov 1965. 30 Nov 1965, 129p. (Contract NAS5-9637) (NASA-CR-74989; P65-149) Xoo-17557.

NOTICE: Available to U.S. Government Agencies and Their Contractors Only.

This report describes the work performed during this period on a parametric analysis of microwave and laser commmunication and tracking systems. Information and conclusions of previous studies were acquired and critiqued. The critiques list the significant contributions of each study and the location of the material within the body of the report. The critiquing has been completed for telecommunications and is in progress for the acquisition and tracking portion. Progress is reported on the three sections of a space design handbook. These sections include a methodology for solving space communication and tracking problems, parametric studies of the parameters involved in the methodology, and a state-of-the-art documentation of the parameters values.

96. Hurst, S. R. et al.
OPTICAL SPACE COMMUNICATIONS SYSTEM STUDY. VOLUME 1: SUMMARY, CONCLUSIONS, RECOMMENDATIONS. General Electric Co., Valley Forge Space Technology Center, Philadelphia, Pa. Final Report, Mar 1964, 36p. (NASA Contract NASw-540) (NASA-CR-53636). N64-19990.

The ultimate potential of optical space communication and the problems of realization are discussed. Overall conclusions and recommendations are presented. Performance of a preliminary analysis of three assigned missions, with the object of identifying the salient advantages and problem areas of optical communication was summarized. A wide variety of environmental and equipment factors are also summarized. To assess the ultimate potential of an optical communication system, the theoretical information capacity of a noisy quantized wave was derived. The theoretical performances of the major types of receivers (heterodyne, homodyne, and quantum counter) were analyzed and interpreted. Propagation in the atmosphere and special considerations in low-level photodetection are treated. Selection of heterodyne detection is justified, and component requirements in a heterodyne communication system are analyzed. This system was applied to the following missions of interest, and the performances are calculated: Mars-Earth terminal, Mars-Earth satellite, Moon base-Earth terminal. The results of the performance calculations are presented

97. Institute of Science and Tech., University of Michigan, Ann Arbor, Michigan. IRIA ANNOTATED BIBLIOGRAPHY OF INFRARED LITERATURE. VOLUME VII, NUMBER 4 (CUMULATIVE). Rept. no. 2389 88B, Feb 1964, 104p. Contract Nonr 122412. AD-347 691. (CONF.)

Reports on various aspects of infrared technology which were received in IRIA during the past year are listed by standard IRIA categories. Each listing is annotated topically.

98. International Business Machines Corp., Federal Systems Div., Huntsville, Alabama. LASER AIMING SIMULATION (LASIM). VOLUME 2: PROGRAMMERS AND USERS' MANUAL. Final Repot 20 May 1968, 183p. (Contract NAS8-21033). (NASA-CR-61976; IBM-68-K10-0006. V.2). N68-36227.

Program functions and logic are described to illustrate the use of the laser aiming simulation (LASIM) modularized programs, which are written in double precision FORTRAN 4, version 13, for the IBM 7094 computer. The operation of the fine tracking system, the telescope control system, and the spacecraft attitude control system are simulated by LASIM program subroutines. In addition, simulation of the physical dynamics of the mass elements comprising the laser communications system experiment (LSCE) in response to hardware actuation is accomplished. Simulation of the pointing operation is contained within a separate program called the pointing control program, and is discussed in detail. The functions performed by the LASIM program and major program logic are represented through flow charts.

99. Ito, M. et al. TRANSMISSION OF TELEVISION SIGNALS BY HeNe LASER BEAM THROUGH THE ATMOSPHERE. Journal of Television Engineers, Japan, Jan 1968, pp. 15–22.

Transmitted one TV channel.

100. ITT Communication Systems Inc., Paramus, New Jersey. APPLICABILITY OF LASER TECHNIQUES. Rept. no. ICS-64-TR-480, ICS-64-TR-481. Aug 1964, 283p. Contract AF 19(628)-3414 Task A-1 ESD TR-66-480. AD-486 861L.

101. Jacobs, S. F., J. T. LaTourrette, and G. Gould. HETERODYNE DETECTION IN OPTICAL COMMUNICATION. Final Report. Technical Research Group, Inc., Melville, New York. Jul 1964, 236p. (Contract AF 30(602)-2591.) (RADC-TDR-64-130; AD-603622). N64-27426.

The properties of optical heterodyne detection are analyzed and measured, using a laser and Twyman-Green interferometer. It is shown that heterodyne and amplification preserves the signal-to-noise ratio in the detected difference frequency in the presence of incoherent noise and that the limiting noise of the system is photocurrent shot noise. Suitability of this technique is demonstrated for diffuse as well as specular mirrors and corner reflectors as well as flats. Various techniques of modulation are discussed and demonstrated, including phase, amplitude, and single-sideband modulation. A method is developed for the demodulation of phase-modulated light. The limitations imposed on the optical heterodyne technique by the transmission path conditions are investigated. The uses and limitations of heterodyne detection in optical communications, demultiplexing of channels, demodulation of FM and AM, doppler and displacement measurements, and laser stabilization are discussed.

102. Kazaryan, R. and V. Tatarnikov LASER COMMUNICATIONS TODAY AND TOMORROW. Joint Publications Research Service, Washington, D. C. Trans. of Radio, Moscow (USSR) n8, pp. 14-17, 1970. 12 Oct 1970, 8p. JPRS-51546.

The report covers the feasiblity of using lasers in optical communications systems, noting the performance of certain lasers to be used and the effect that weather might have on the transmission of signals.

103. Karp, S., E. L. O'Neill, and R. M. Gagliardi
COMMUNICATION THEORY FOR THE FREE-SPACE OPTICAL CHANNEL. Proceedings of the IEEE, Vol. 58, No. 10, Oct 1970, pp. 1611–1626.

The current understanding of quantum detectors, the noise mechanisms which limit (are basic to) their operation, and their application to optical communications (theory) is summarized. In this context, we are considering channels in which the electromagnetic field is not subjected to any propagation effects other than a geometric loss. (Such a channel would exist between satellites.) Consequently, we will concentrate on optimum time processing using the tools of statistical communication theory.

Fundamental to the study of a detection process is the need to develop a good mathematical model to describe it (1)–(6). Therefore, approximately one-fifth of the paper is devoted to establishing, in a semi-classical analysis, the quantum detector output electron number as a conditional Poisson process with the conditioning variable being the modulus of the electromagnetic field. Once this has been established, these results are used to derive various limiting probability densities related to actual practice. Although the mathematical details are omitted, these results will be presented from the viewpoint of orthogonal function expansions and interpreted in terms of an eigenspace.

The resulting current flow is analyzed next as a shot noise process, and the power density spectrum is calculated. Attention is focused on isolating the signal components from the noise in terms of both the current probability density and the power density spectrum. Examples are given where appropriate. At this point, an understanding of the underlying noise processes will have been presented and attention will shift to analog and digital communications.

The analog communication will be presented primarily in terms of the signal-to-noise ratio. The S/N ratio in direct detection will be presented both as a ratio of the integrals of two separate portions of the spectrum and as a ratio of two moments of the probability density describing the current. These calculations will be extended to include heterodyne detection.

Digital communications will be discussed in the context of detection theory. It will be shown that the likelihood ratio is often a monotonic function of the random variable representing the number of electrons flowing. Hence optimum processing will consist of a weighted count of electrons from various counting modes. Digital design will be presented in terms of M-ary signaling, error probabilities and information rates.

104. Karp, S. and R. M. Gagliardi
THE DESIGN OF A PULSE POSITION MODULATED (PPM) OPTICAL COMMUNICATION SYSTEM.
National Aeronautics and Space Administration, Electronics Research Center, Cambridge, Mass.
Oct 1968, 25p. (NASA-TN-D-4814). N68-35174.

In recent literature the advantages of an idealized narrow width pulse position modulated (PPM) optical communication system, using coherent sources and direct photodetection, have been shown. In this report, the practical design of such an operating PPM link is considered. System performance, in terms of error probabilities and information rates, are derived in terms of key parameters, such as power levels, number of PPM signals, pulse width, and bandwidths. Both background radiation and receiver thermal noise are included. Design procedures utilizing these data are outlined. Whenever possible, optimal design values of parameter trade-offs, in terms of maximizing information rate or minimizing transmitter power, are shown. The effect on performance of photomultipliers and their inherent statistics is also presented. Although the basic analysis is derived in terms of photon counts, the necessary system optics equations are introduced to allow for overall optical hardware design. The primary underlying assumption is that synchronization is maintained at all times between transmitter and receiver.

105. Karp, S. and R. M. Gagliardi
M-ARY POISSON DETECTION AND OPTICAL COMMUNICATIONS. National Aeronautics and Space Administration, Electronic Research Center, Cambridge, Mass. Jun 1968, 26p. (NASA-TN-D-4623). N68-29528.

This report presents an investigation of the problem of maximum likelihood detection of one of M Poisson processes in a background of additive Poisson noise. When the observables correspond to counts of emitted photoelectrons, the problem models a discrete version of a coherent M-ary optical communication system using photon counters in the presence of background radiation. Consideration is given to an average distance and a detection probability criterion. The advantages of an M-ary - pulsed intensity set (Poisson intensities wholly concentrated in a single counting interval) are demonstrated. The performance of such intensity sets is exhibited in terms of error probabilities, pulse widths, signal-to-noise ratio, and channel capacity. Behavior as a function of number of intensities M is also discussed. By appropriate conversion these latter results may be used for determining power requirements in an optical pulse position modulation system.

106. Kerr, J. R., P. J. Titterton, and A. R. Kraemer
ATMOSPHERIC OPTICAL COMMUNICATIONS SYSTEMS. Proceedings of the IEEE, Vol. 58, No. 10, Oct 1970, pp. 1691–1709.

The increasing sophistication of optical (and infrared) components and techniques, combined with rapidly expanding communication requirements, suggests that optical systems operating partly or entirely within the atmosphere may soon represent desirable solutions to real communications problems. The design of such systems will be strongly influenced by considerations of atmospheric turbulence, molecular absorption, and aerosol scattering. The most promising alternatives are heterodyne systems operating at the 10.6 μ wavelength, and direct-detection systems at near-infrared or visible wavelengths. Feasible links include horizontal, ground-to-satellite, and satellite-to-ground (or aircraft) geometries.

System requirements and atmospheric effects are reviewed. Components, signaling, and diversity techniques which will partially overcome atmospheric limitations are discussed. Specific representative systems designs are presented.

107. Kerr, J. R.
MICROWAVE-BANDWIDTH OPTICAL RECEIVER SYSTEMS. Proceedings of the IEEE, Vol. 55, No. 10, Oct 1967, pp. 1686–1700.

A theoretical and experimental evaluation of optical communications systems capable of microwave bandwidths is presented. The optical transmitter, modulator, and detection techniques are discussed with respect to both direct-detection and optical heterodyne receivers, and experiments in a nonlaboratory environment are described. At the high optical power levels or photon rates which are fundamentally necessary for gigahertz instantaneous bandwidths, it is found that signal-shot-noise limited operation may be obtained with new wideband photodetectors incorporating internal gain. Direct-detection receivers are thus generally superior to heterodyne receivers in these systems. A comparison is made of the relative merits of alternative systems and their dependence on various parameters such as information capacity, range, and background illumination.

108. Kerr, J. R.
MICROWAVE OPTICAL RECEIVER TECHNIQUES.
Electronic Defense Labs., Sylvania Electronic Systems-West, Mountain View, California.
Interim engineering rept. no. 2, 1 Sep–30 Nov 1965. 30 Nov 1965, 62p. Contract AF33(615)-3108. AD-625 382.

The report presents the results of the second quarter of effort on a one-year applied research program on the use of various techniques for microwave optical communications through the atmosphere. The relative theoretical advantages of direct and heterodyne optical receivers are considered further, and some popular misconceptions about the nature of background noise are pointed out. Further consideration is also given to modulation and information processing techniques and to the use of multimode lasers in the microwave-bandwidth systems. Specific systems are recommended which incorporate present techniques in an optimum manner. A comprehensive experimental program of direct-detection microwave-optical communications over an outdoor path has shown that the multiplier phototubes developed in this laboratory can achieve excellent results with minimum operating difficulty.

109. Kerr, J. R.
MULTIWAVELENGTH LASER PROPAGATION STUDY. II. Oregon Graduate Center for Study and Research, Portland, Oregon. Quarterly progress rept. no. 3, 15 Dec 1969–15 Mar 1970. Rept. no. 1154-7. Apr 1970, 38p. Contract N00014-68-A-0461-0001, ARPA Order-306. AD-704 535.

A series of significant multiwavelength laser propagation experiments were conducted with point-source transmitters and independent determinations of turbulence strengths. Under non-saturate scintillation conditions, it was found that the theoretical wavelength prediction of log amplitude variance is valid. Also, it was found that the near and far-infrared wavelengths do not saturate at lower variances than visible wavelengths, and large infrared variances have been measured. It was found that different techniques for measuring the strength of turbulence yield different (out related) results. It was found that the multiwavelength covariance characteristics are usually independent of conditions and are near theoretical values, although certain anomalous results suggest limitations in the extent of the inertial subrange turbulence model. It was found that large receiver apertures do not result in the degree of reduction in total signal fluctuations that would be expected from the theory. Finally, it was found that simultaneous records of changing variances and turbulence strengths yield interesting characteristics which may be related to the stationarity of the medium.

110. Khodarev, Yu. K.
SPACE COMMUNICATIONS SYSTEMS AND INFORMATION TRANSMISSION. Joint Publications Research Service, Washington, D.C. Transl. into English from Kosmich, Issled. (Moscow). v. 5, no. 5, 1967, pp. 680–685. 21 Feb 1968, 9p. (JPRS-44962). N68-16350.

A chronological account is presented on the development of space communications systems, starting with the launch of the first Sputnik in October 1957. Also discussed is an experimental communication syst m, initiated in 1965, which provides multichannel telephone-telegraph duplex communication and television transmission; remote interplanetary communication; telemetry data transmission; required energy levels for onboard power sources; optical communication; and onboard-data processing.

111. Kinsel, T. S. and R. T. Dentron
TERMINALS FOR A HIGH-SPEED OPTICAL PULSE CODE MODULATION COMMUNICATION SYSTEM: II. OPTICAL MULTIPLEXING AND DEMULTIPLEXING. Proceedings of the IEEE, Vo' 56, No. 2, Feb 1968, pp. 146–154.

Techniques are described for optically multiplexing and demultiplexing individual pulse code modulation channels in order to develop the terminal capability for a high-capacity optical communication system. It is shown that, using these techniques, an information capacity in excess of 10^{10} bit/s can be achieved on the output beam of a single laser.

112. Kinsel, T. S.
WIDE-BAND OPTICAL COMMUNICATION SYSTEMS: PART I – TIME DIVISION MULTIPLEXING. Proceedings of the IEEE, Vol. 58, No. 10, Oct 1970, pp. 1666–1683.

The purpose of this paper is to consider the theoretical error performance of several digital formats suitable for use with a mode-locked laser source, to discuss the problems of implementing these formats, and to consider the design of an illustrative system. Several techniques for time multiplexing are also described. It is assumed that the transmission medium introduces only additive noise and that the detection process is signal shot noise limited. Among the formats examined the practical choices which can achieve highest information rates with lowest probabilities of error

are binary, differential phase shift keying, and binary pulse position modulation. For purposes of illustrating state-of-the-art performance the design of a 4000-mile repeatered binary pulse code modulation intensity modulated system is outlined.

113. Kliphuis, J. and J. C. Greene
LOW-NOISE, WIDEBAND, UNCOOLED PREAMPLIFIER.
IN: American Institute of Aeronautics and Astronautics, Communications Satellite Systems Conference, 3rd, Los Angeles, Calif., Apr 6-8, 1970, Paper 70-419, 5p.

Description of the theory, design, and measured performance characteristics of a wideband, low-noise, uncooled preamplifier system for use in small unattended satellite communication receiving terminals such as those now envisioned for Comsat's pilot program and for the Canadian domestic program. The preamplifier contains four identical wideband parametric amplifier stages in cascade. Each stage provides a gain of 10 dB and the resulting overall net gain of 40 dB is flat within plus or minus 0.5 dB over the entire 3.7 to 4.2-GHz band consistent with an overall noise temperature, including the loss of an optional input 5.925 to 6.425-GHz transmitter-reject filter, that is below 100K. The parametric amplifier stages are temperature-stabilized by means of a solid-state thermoelectric heater/cooler element that maintains the amplifier modules near 35°F as the ambient temperature varies from -25 to +125°F. By this means, long-term gain stability is obtained, without sacrificing noise performance, over the large range of ambinet temperatures normally encountered in unattended earth stations. A simple solid-state pump source has been developed for the preamplifier to minimize power requirements and to enhance reliability and operating life. Detailed performance measurements are given for IM products, overload level, VSWR, etc.

114. Kolosov, Iu. A.
COMPARISON OF THE SENSITIVITIES OF OPTIMAL OPTICAL-BAND RECEIVERS (Sravnenie chuvstvitel'nostei optimal'nykh priemnikov opticheskogo diapazonal).
Radiotekhnika i Elektronika, vol. 15, Aug 1970, pp. 1672-1677. In Russian.

Investigation of certain questions regarding optimal postdetector treatment of a continuous, determinate, amplitude-modulated, optical-band signal. Expressions are obtained for the sensitivities of an optimal direct-photodetection receiver and an optimal superhetrodyne receiver for the cases of determinate and random envelope phases ensuring given detection characteristics.

115. Kopeika, N. S. and J. Bordogna
BACKGROUND NOISE IN OPTICAL COMMUNICATION SYSTEMS. Proceedings of the IEEE, Vol. 58, No. 10, Oct 1970, pp. 1571–1577.

The origin and magnitude of the several kinds of background noise that perturb optical communication receivers are discussed, including background radiation sources viewed directly, radiation reflected from background objects, and radiation scattered by the atmosphere into the receiver field of view. An extensive bibliography on this topic is presented.

116. Kozliaev, I. P., V. V. Nikitin, and V. S. Samoilov
APPLICATION OF LOGIC ELEMENTS MADE OF INJECTION LASERS IN COMMUNICATIONS SYSTEMS WITH TIME DIVISION MULTIPLEX (Ispol'zovanie logicheskikh elementov na inzhektsionnyky lazerakh v sistemakh opticheskoi sviazi s vremennym uploteniem). Radiotekhnika i Elektronika, vol. 15, Apr 1970, pp. 772–777. 7 refs. In Russian.

Experimental data for the use of injection lasers as logic elements in optical communication systems employing time division multiplexing of light pulses. Recommendations are given for the optimal switching of the laser diodes into a coherent-emission regime, and methods of reducing the pulse durations are examined. It is shown that the use of the proposed laser elements makes it possible to obtain information transfer rates of about 10 to the 10th power bits/sec.

117. Kraemer, A. R. and C. R. Cooke
OPTICAL COMMUNICATIONS IN SPACE.
IN: NAECON '70; Institute of Electrical and Electronics Engineers, National Aerospace Electronics Conference, Dayton, Ohio, May 18–20, 1970. Proceedings. Dayton, Ohio, Institute of Electrical and Electronics Engineers, Inc., 1970, pp. 405–412. 10 refs.

Recent development in low power, high efficiency Nd and CO_2 laser sources as well as space qualification programs currently underway bring the prospect of spaceborne optical communications closer to reality. Based on the current state-of-the-art,

optical communication systems can be competitive with current microwave and planned EHF technology with regard to size, weight, and power. Other unique properties of optical communications can be employed to advantage to satisfy certain communication requirements such as extremely high data rates, privacy, resistance to jamming, and operation in a nuclear environment. This paper presents a representative optical communication system design identifying pertinent parameters such as size, weight, power, and attainable data rates. The design will be developed from a brief trade-off analysis also presented. Emphasis will be placed on the important area of acquisition and autotracking.

118. Kurtz, R. L. and J. L. Hayes
EXPERIMENTAL MEASUREMENT OF OPTICAL ANGULAR DEVIATION CAUSED BY ATMOSPHERIC TURBULENCE AND REFRACTION. National Aeronautics and Space Administration, Marshall Space Flight Center, Huntsville, Alabama. May 1966, 60p. (NASA-TN-D-3439). N66-25558.

Atmospheric turbulence causes the image of a stationary optical source to fluctuate in intensity and position. The amplitude and frequency of this random position fluctuation have been measured. Data were recorded over a period of approximately six months and over two different path lengths. The system and site are described. Data are analyzed and tabulated to show the amplitude of fluctuations in various meteorological conditions. A sample of these data is statistically analyzed to determine the limitations of an optical tracking system.

119. Ksander, Y.
SOVIET QUANTUM ELECTRONICS RESEARCH: COMPREHENSIVE REPORT. Library of Congress, Aerospace Technology Div., Washington, D.C. Report on Surveys of Foreign Scientific and Technical Literature. Rept. no. ATD-66-97. 2 Aug 1966, 132p. AD-643 937.

The report reviews Soviet and Soviet-bloc laser research as reflected in the open scientific literature published in the USSR and the bloc countries. The report is the second in the series and is based on 634 research and review papers which cover the period from September 1964 through February 1966, i.e., eighteen months. The first appeared as ATD Report P-65-23 (AD-615 177) and covered the period from January 1961 through August 1964. The review is divided into sections, each section covering the work of a particular organization (a research institute, a laboratory, or

university). These sections are, in most cases, subdivided into specialized subject areas. The review sections are arranged in the order in which they are discussed in the sections and are keyed to the appropriate review section by letter designation.

120. Lally, E. F.
STUDY OF CONCEPTUAL DEEP SPACE MONITOR COMMUNICATIONS SYSTEMS USING A SINGLE EARTH SATELLITE. VOLUME II: INTERFACE RELATIONSHIPS, TRADEOFF AND ANALYSIS AND STUDY RESULTS. Space-General Corp., El Monte, Calif. Final Report. Sep 1966, 89p. (Contract NAS2-3179). (NASA-CR-73035; SGC-920FR-1, Vol. II). N67-17840.

Reported are results of a study designed to determine the feasibility and capability of concepts for deep-space communications employing single earth satellites; to perform parametric analyses to indicate the more promising integrated system concepts; and to expose technical problem areas and indicate how such problem areas can influence the choice and performance of candidate systems. The study resulted in a parametric analysis of deep space monitor communication systems consisting of a single earth satellite and associated interplanetary spacecraft. The accomplishment of the study objectives required parametric analyses involving considerations of frequency, bandwidth, radiated power, data rate, antenna size, weight, and volume, and orbit inclination and altitude. Evaluation of support requirements were also necessary as were antenna fabrication and deployment, equipment modules, attitude control, power sources, micrometeoroid dust and radiation shielding, launch vehicles and site selection, and logistics and resupply Considerations were given to system integration and tradeoffs as required to monitor both manned and unmanned spacecraft for planetary missions.

121. Laurie, K. A. and M. M. Hale
FOLDED-PATH ATMOSPHERIC-PRESSURE CO_2 LASER. Defence Research Establishment, Valcartier, Quebec. Rept. no. DREV-Reprint-44/70. 19 Mar 1970, 4p. Revision of report dated 9 Feb 1970. AD-714 440.

Availability: Pub. in IEEE Jnl. of Quantum Electronics, vQE6, n. 8, pp. 530-532, Aug 1970. No copies furnished.

A folded-path transversely excited atmospheric-pressure CO_2 laser utilizing shower or brush discharges is described. The output pulse has an initial peak 0.4 microsec wide followed by a tail 2–3 microsec long. A peak powder of 0.2 MW with 4.4 percent efficiency is obtained. By rotating one of the mirrors of the resonator the tail is eliminated, yielding a pulse 0.2 microsec wide of the same peak power.

122. Laurie, K. A.
GALLIUM ARSENIDE LASER RANGEFINDER PERFORMANCE. Defence Research Establishment, Valcartier, Quebec. Rept. no. DREV-599/69. Oct 1969, 44p. AD-868 209.

The range performance of a gallium arsenide laser rangefinder subject to atmospheric attenuation has been calculated for peak transmitted powers of one, ten and one hundred watts, assuming pulse-to-pulse integration of up to 10,000 pulses. As it was desirable that the rangefinder be small and lightweight, a photodiode detector and a five-centimeter diameter receiver objective were assumed. This aperture-detector combination resulted in the rangefinder being detector-limited rather than background-limited.

123. Lawrence, R. S. and J. W. Strohbehn
A SURVEY OF CLEAR-AIR PROPAGATION EFFECTS RELEVANT TO OPTICAL COMMUNICATIONS. Proceedings of the IEEE, Vol. 58, No. 10, Oct 1970, pp. 1523–1545.

The theory and observations of the optical propagation effects of the clear turbulent atmosphere are reviwed, with particular attention to those characteristics most important to the designer of an optical communication system. Among the phenomena considered are the variance, probability distribution, spatial covariance, aperture smoothing, and temporal power spectrum of intensity fluctuations, and similar quantities for phase fluctuations and angle of arrival.

124. Leverenz, D. J. and O. L. Gaddy
SUBNANOSECOND GATING PROPERTIES OF THE DYNAMIC CROSS-FIELD PHOTOMULTIPLIER.
Proceedings of the IEEE, Vol. 58, No. 10, Oct 1970, pp. 1487–1490.

Experimentally measured characteristics of the sampling function in the dynamic cross-field photomultiplier are presented. A self-mode-locked He-Ne laser with a pulse-repetition rate nearly equal to the photomultiplier sampling rate is used to determine the sampling characteristics of this device. Experiments with a device with two regions in which different dc fields can be established are also reported. With this device, sampling intervals of less than 10 percent of the RF electric field period can be obtained with very little reduction in gain compared to conditions yielding broader sampling intervals.

125. Lipsett, M. S.
LASER OPTICS TECHNIQUES. Perkin-Elmer Corp., Norwalk, Conn. IN: NASA, Marshall Space Flight Center Space Opt. Technol. Conf., Vol. 2, Apr 1966, pp. 109–124. X68-181888.

NOTICE: Available to U.S. Government Agencies and Their Contractors Only.

Studies of the practical factors influencing the design of a future space worthy optical communication system are reported. A realistic communication system breadboard is being developed with experimental studies of the following areas: stability of laser beam intensity distribution in the far field; remote boresight alignment of receiving and transmitting optical channels; isolation of the transmitter channel from the receiver channel; determination of a rotational coordinate reference system about the line of sight; and implementation of fine guidance tracking and pointing offset capabilities. The system breadboard employs a 40.64 cm aperture diffraction limited telescope. A helium neon laser functions as the spaceborne transmitter, and the guidance optics and detectors are designed for use with a distant argon laser beam.

126. Lipsett, M. S.
LASER/OPTICS TECHNIQUES. Perkin-Elmer Corp., Electro-Optical Div., Norwalk, Conn. Summary Report. 29 Apr 1966, 257p. Its Eng. Rept.-8387. (Contract NAS8-20115). (NASA-CR-77482). N66-35245.

Laser and optical techniques applicable to future deep space optical communication systems are discussed. Analysis and laboratory work have been conducted in the following areas: stability of laser beam intensity distribution in the far field; remote boresight alignment of receiving and transmitting optical channels; isolation of the transmitter channel from the receiver channel; determination of a rotational coordinate reference system about the line of sight; and ways of implementing fine guidance tracking and pointing offset capabilities. Laboratory breadboard equipment, which was developed as building blocks, is described, and a summary of project activities to date is presented. Fluctuations in the far field of a He-Ne laser are shown to be of insufficient magnitude to be detrimental to an optical communication link. Further, it is shown that, by special dielectric multilayer filter techniques, channel isolation of at least 115 dB is readily achieved for the purpose of optical duplexing.

127. Lipsett, M. S.
LASER/OPTICS TECHNIQUES. Perkin-Elmer Corp., Optical Group, Norwalk, Conn. Interim Summary Report. 30 Apr 1968, 136p. (Contract NAS8-20115). (NASA-CR-98117); Rept. 9365; IR-3). N69-11259.

Design and manufacturing details are provided on a laboratory prototype communications system, consisting of a laser telescope communications package and a four-axis mount to be operated in conjunction with an earth beacon simulator. The transceiver optical configuration was redesigned to show the feasibility of adapting the system for a transmitter wavelength of 10.6 microns. The key optical components were made reflective and independent of operating wavelength or laser choice. A fine guidance system was developed to combine the optical efficiency of an optical image splitter with the compactness and reliability of a quadrant multiplier phototube. Instrumentation weight was minimized, and the instrument package was made more compact. Also developed was instrumentation for testing laser telescope performance under simulated space conditions. The factors contributing to scattered light are assessed, and criteria are given on selecting substrate materials for infrared and visible dichroic beamsplitters. An overview is included on several solid state modulators proposed for CO_2 laser light.

128. Lipsett, M. S.
LASER/OPTICS TECHNIQUES. Perkin-Elmer Corp., Optical Group, Norwalk, Conn Second Interim Summary Report, 31 Dec 1966, 68p. (Contract NAS8-20115). (NASA-CR-81701; Rept. 8631). N67-18023.

The development of transmit beam offset and coarse acquisition equipment for the Laser/Optics Techniques breadboard is described. In addition, preliminary acquisition and track simulation experiments carried out in the laboratory with the breadboard hardware are discussed.

129. Lipsett, M. S., C. M. McIntyre, and R. C. Liu
SPACE INSTRUMENTATION FOR LASER COMMUNICATION. IN: Electro-Optical Systems Design Conference, 1st, New York, N. Y. September 16-18, 1969, Proceedings. Edited by K. A. Kopetzky, Chicago, Industrial and Scientific Conference Management, Inc., 1970, pp. 804-810, 5 refs. Contracts No. NAS8-20115; No. NAS8-20841.

Detailed description of the terminals developed for a deep space optical communications link. The experimental results are summarized that demonstrate the achievement of the precise pointing accuracies necessary to take advantage of the extremely narrow beamwidths available from a diffraction-limited laser telescope. The link was designed for operation at ranges exceeding 100 million miles (Martian distances) and with data rates of one million bits/second. An operational prototype of the flight hardware for the spaceborne terminal has been fabricated, and the experiments were performed using this prototype. A ground station, to be used in conjunction with the prototype or other optical transceivers, has also been fabricated and is described.

130. Lucy, R. F.
DEVELOPMENT OF AN OPTICAL SUPERHETERODYNE RECEIVER. Sylvania Electric Products, Inc., Applied Research Lab., Waltham, Mass. Final Report, Mar 1968, 288p. (Contract NAS8-11588). (NASA-CR-61711). X68-14684.

NOTICE: Availabe to U.S. Government Agencies and Their Contractors Only.

An operational model of an automatic tracking optical superheterodyne receiver was designed and tested for use in communication experiments comparing noncoherent and coherent detection in a real atmospheric environment at 6328Å. Typical fading data were obtained and noncoherent techniques were found to be superior to coherent methods. Two different laser communications systems were promising for use in deep space communications; and in the visible and near infrared a ground-based noncoherent receiver provided useful wideband communications with a spacecraft-borne transmitter, while in the far infrared a coherent receiver also provided high data rate communications. Two optical tracking experiments were performed; one of which involved a ground-to-space-to-ground laser communications experiment to passively acquire and illuminate the retroreflector type satellite Explorer 22 with CW laser radiation and to monitor the reflected intensity. A study was made to determine preferred transmitter modulation methods that could be used in optical communication experiments.

131. Lucy, R. F.
LARGE APERTURE SEGMENTED OPTICS FOR SPACE-TO-GROUND COMMUNICATIONS.
Applied Optics, Vol. 7, Aug 1968, pp. 1571–1576, 22 refs.

Design of a large-aperture, moderate-quality segmented optical array for use in noncoherent space-to-ground laser communications as a function of resolution, diameter, focal length, and number of segments in the array. Secondary optics and construction tolerances are also discussed. Performance predictions show a typical receiver to be capable of 1 MHz bandwidth communications at Mars distances during daylight operation.

132. Lucy, R. F., K. Lang, and C. J. Peters
OPTICAL SUPERHETERODYNE RECEIVER.
Applied Optics, Vol. 6, No. 8, Aug 1967, p. 1333.

Optical communications experiments at 6328 Å, comparing the fading characteristics of coherent and noncoherent optical detection, have been performed over a 1-km real atmospheric path in different weather conditions. The results show that fading is less severe for noncoherent detection and that the fading characteristic for both types vary significantly with weather conditions. In addition, the similarity of optical FM to rf FM is demonstrated. The measurements were performed using a remote laser transmitter and an optical superheterodyne receiver operating simultaneously in both a coherent and noncoherent detection mode. The receiver, tunable over a frequency range of 1 GHz at the IF difference frequency of 30 MHz, has automatic frequency control and also uses a precision angle tracking servo to maintain receiver spatial alignment with a remote transmitter. The angle and frequency tracking capability permit operation between moving transmitter and receiver terminals.

133. Lucy, R. F., C. J. Peters, and E. J. McGann
PRECISION LASER AUTOMATIC TRACKING SYSTEM. Sylvania Electric Products, Inc., Sylvania Electronic Systems Div., Applied Research Laboratory, Waltham, Mass. Applied Optics, vol. 5, Apr 1966, pp. 517–524, 14 refs. NASA-sponsored research.

A precision laser tracker has been constructed and tested that is capable of tracking a low-acceleration target to an accuracy of about 25 μ rad root mean square. In tracking high-acceleration targets, the error is directly proportional to the angular acceleration. For an angular acceleration of 0.6 rad/sec^2, the measured tracking error was

about 0.1 mrad. The basic components in this tracker, similar in configuration to a heliostat, are a laser and an image dissector, which are mounted on a stationary frame, and a servo-controlled tracking mirror. The daytime sensitivity of this system is approximately 3×10^{-10} watts/m^2; the ultimate nighttime sensitivity is approximately 3×10^{-14} watts/m^2. Experimental tests were performed to evaluate both dynamic characteristics of this system and the system sensitivity. Dynamic performance of the system was obtained, using a small rocket covered with retroreflective material launched at an acceleration of about 13 g at a point 204 m from the tracker. The daytime sensitivity of the system was checked, using an efficient retroreflector mounted on a light aircraft. This aircraft was tracked out to a maximum range of 15 km, which checked the daytime sensitivity of the system measured by other means. The system also has been used to track passively stars and the Echo 1 satellite. Also, the system tracked passively a +7.5 magnitude star, and the signal-to-noise ratio in this experiment indicates that it should be possible to track a +12.5 magnitude star.

134. McAvoy, N., H. L. Richard, and J. H. McElroy
10.6 MICRON LASER COMMUNICATIONS SYSTEM EXPERIMENT FOR ATS-F AND ATS-G. National Aeronautics and Space Administration, Goddard Space Flight Center, Greenbelt, Md. May 1968, 72p. (NASA TM-X-63233; X-524-68-206). N68-25773.

The purpose of the coherent laser satellite-to-satellite experiment proposed for the ATS-F and -G program is to use the present laser state-of-the-art to establish the feasibility and value of optical space communications. Identical 23-pound tranceivers will be placed on ATS-F and -G, each consuming 20 watts of prime power. Information will be imposed on a frequency-modulated 10.6-micron carbon-dioxide laser beam within a 30-MHz bandwidth. A superheterodyne receiver with a 12.6-dB noise figure will be used at each end of the link. A 5-inch-aperture optical antenna with a 100-dB antenna gain and a 400-mw carrier, will provide a 28-dB signal-to-noise ratio. The experiment, incorporating components and subsystems tested in the laboratory and field, will be the first complete laser space-communications link. By establishing the above-mentioned weight, power levels, signal-to-noise ratio, and bandwidth and by testing its performance in actual space operation, the engineering parameters necessary to meet NASA requirements for future applications to deep-space distances or for earth-orbital missions with information capacity far greater than the 30 MHz proposed here can be realistically predicted. A single 5-inch viewing port through the skin of the 30-foot antenna, used for both transmitting and receiving, will not interfere with the structure of the antenna pattern. Optical auto-tracking, sufficiently accurate to benefit from the intrinsic high gain of the optical antenna, will supplement pointing of the optical axis with respect to the ATS geostabilization.

135. McElroy, J. H.
CARBON DIOXIDE LASER SYSTEMS FOR SPACE COMMUNICATIONS. IN: Institute of Electrical and Electronics Engineers, International Conference on Communications, San Francisco, Calif., Jun 8-10, 1970, Proceedings. Volume 1. Edited by Donald Green, New York, Institute of Electrical and Electronics Engineers, Inc. (Conference Record, Volume 6), 1970, pp. 22-27 to 22-37. 48 refs.

Analysis of four communication links in which carbon dioxide laser systems might be employed. The communication links are: synchronous satellite to ground, low-altitude satellite to synchronous satellite, synchronous satellite to synchronous satellite, and Mars probe to either a ground station or a synchronous satellite. Five key technological areas are reviewed: carbon dioxide laser transmitters, modulators, wideband receivers, optical antennas, and acquisition and tracking. The ATS-F Laser Communication Experiment, the first carbon dioxide laser communication system scheduled to be placed in orbit, is reviewed. Its characteristics are discussed with regard to growth potential for future more advanced and operational systems.

136. McElroy, J. H.
DC-BIASED PHOTOCONDUCTIVE DETECTION OF WIDEBAND CARBON DIOXIDE LASER SIGNALS. National Aeronautics and Space Administration, Goddard Space Flight Center, Greenbelt, Md. Feb 1968, 66p. (NASA-TM-X-63336; X524-68-54). N68-36032.

The application of dc-biased photoconductive detectors to the reception of wideband CO_2 laser signals is described. Signal-to-noise power ratios in the detection of AM, PM, and FM, by photomixing are derived and the dependence of both signal and noise is shown. Expressions are given for the maximum tolerable mechanical vibration amplitude in a photomixing system and for the beam alignment requirements. Local oscillator power requirements are then discussed and it is shown that no less than 10 mw are required to assure g-r noise limited operation in a typical extrinsic germanium photoconductor. Measurement techniques are then described from which detector quantum efficiency, majority carrier lifetime, and mobility can be determined.

137. McGraw-Hill Informatica Systems Co., Wright-Patterson AFB, Ohio.
SOVIET RESEARCH ON LASER BEAM PROPAGATION IN THE ATMOSPHERE. Rept. for Jun 1968 – Dec 1969. Rept. no. MHR-70-11, 15 Jun 1970, 36p. Contract F33657-70-C-0023. AD-512 107. (CONF.)

138. McIntyre, C., W. N. Peters, and C. Chi
OPTICAL COMPONENTS AND TECHNOLOGY IN LASER SPACE COMMUNICATIONS SYSTEMS.
Proceedings of the IEEE, Vol. 58, No. 10, Oct 1970, pp. 1491–1503.

Passive linear optical components play a primary role in an optical communications system for use in space applications. The important functions of acquisition, tracking, transmit-beam offset, and background-noise discrimination may be efficiently implemented using passive optical elements. These specific system functions are discussed with reference to a representative system in order to identify the required features of particular optical components. This is followed by a detailed discussion of the optical components including: a 1/2-Å Fabry-Perot filter; a transfer-lends/optical-image-divider combination capable of 0.1-second of arc tracking accuracy; variable deviation wedges for transmit-beam offset; dichroic beamsplitters for isolation between the transmit and receive beams; and an axicon for redistributing the Gaussian energy profile from a TEM_{00}-mode laser to match the obscured circular aperture of a conventional Cassegrainian telescope.

139. McMurty, B. J , J. E. Gaenzle, and R. Targ
RESEARCH ON TECHNIQUES FOR LIGHT MODULATION DETECTION. Sylvania Electric Products Inc., Mountain View, Calif. Interim engineering rept. no. 2, 1 Sep–1 Dec 1962, 1 Dec 1962, 47p. 16 refs. (Contract AF 33(657)8995). AD-292 035.

A continuing comparison of light detection schemes has reaffirmed the conclusion that the microwave phototube is the most promising method to detect light modulation. Progress is described in the following areas: (1) theoretical analysis of microwave phototubes; (2) microwave phototube construction, including photosurface preparation and evaluation, and (3) experimental measurements on microwave phototubes, and comparison with theory.

140. Marquis, D. C.
OPTICAL TRACKING – A BRIEF SUMMARY OF THE FIELD. Applied Optics, vol. 5, Apr 1966, pp. 481–487.

Review of the field of optical tracking, including systems, techniques, categories, and applications currently in use. A brief history of the development of optical tracking is given. Positional information can be provided by two general classes of systems – open-loop and closed-loop systems. Optical trackers can also be classified into two general types, one of which is active and involves illumination of the target by an optical transmitter, whereas the other is passive and depends on the reflected and self-radiated power from the target to provide a trackable source. Spectral filtering as a discrimination technique is described. While active optical systems have been limited by power limitations, laser sources hold promise of overcoming this difficulty.

141. Martel, B. E., D. T. Bell, and R. H. Williams
OPTICAL CORRELATION TECHNIQUES FOR WEAK-SIGNAL DETECTION. Texas Instruments Inc., Dallas, Texas. Final rept., 1 Jul 1963–30 Jun 1964. Rept. no. C2 802500 2, 10 Sep 1964, 82p. Contract AF33 657 11367, AL TDR64 213. AD-353 382. (CONF.)

The results of a one-year program to advance the application of optical signal processing techniques to weak-signal communications are presented. The basic principles of optical signal processing are reviewed and application of the techniques developed to an actucal communications system are considered. Progress in technique areas critical to the design of a successful optical correlator such as diffraction-limited optical systems, ultrasonic light modulators, wideband amplifiers, coherent light sources, and photodetectors is described. The operation and evaluation of the breadboard developed on this program is described and recommendations are made for continued work in view of favorable results to date.

142. Massachusetts Inst. of Tech., Lincoln Lab., Lexington, Kentucky.
UNCLASSIFIED PUBLICATIONS OF LINCOLN LABORATORY. SUPPLEMENT 1. Bibliography 15 Sep 1966 – 15 Apr 1967. Supplement 1 to Rept. no. ESD-TR-66-239 dated 15 Sep 1966, AD-803 845. 15 Apr 1967, 44p. Contract AF 19(628)-5167. ESD TR-67-236. AD-816 312.

This list of Unclassified Publications of Lincoln Laboratory is the first Supplement to the 15 September 1966 edition, which should be retained until a new cumulative listing is published. All reports listed herein are deposited with DDC. Since January 1965, Journal Articles and Meeting Speeches (when reprints are available) have also been deposited with DDC. Out-of-print unclassified (released) Lincoln Laboratory reports are available, as microfilm or photoprint copies, from the Microreproduction Laboratory, Hayden Memorial Library, Massachusetts Institute of Technology, Cambridge, Massachusetts 02139. Requests should cite the appropriate serial numbers and prices.

143. Masuda, T., T. Uchida, and Y. Ueno
AN EXPERIMENTAL HIGH-SPEED PCM/AM OPTICAL COMMUNICATION SYSTEM USING MODE-LOCKED He-Ne GAS LASERS. IN: Institute of Electrical and Electronics Engineers, International Conference on Communications, San Francisco, Calif., Jun 8-10, 1970, Proceedings. Volume 2. Edited by Donald Green. New York, Institute of Electrical and Electronics Engineers, Inc., (Conference Record, Volume 6), 1970, pp. 37-13 to 37-23.

Description of a wideband optical communication system using a high-speed optical pulse train emitted from a forcedly mode-locked He-Ne gas laser, which has been installed in 1969 in Japan. The route of this system consists of four spans, and its total length is about 14 km. The repeater stations have pulse regeneration equipments. The bit rate of the transmission speed is 123.492 Mb/s. The system is able to simultaneously transmit 2CH monochromatic TV signals, 1CH high-speed FAX signal, 2CH high fidelity sound signals, 1CH PCM-24 voice signal, and 1 CH pseudorandom pulse signal for measuring bit error rate. Experimental results show that the reliability of the laser communication system with a span length less than two or three kilometers will reach about 99% in a year, which may satisfy industrial uses.

144. Mazo, J. E. and J. Salz
CARRIER ACQUISITION FOR COHERENT DEMODULATION OF PULSE-AMPLITUDE MODULATION.
IEEE Transactions on Communication Technology,
vol. COM-18, Aug 1970, pp. 353-360, 18 refs.

Discussion of phase recovery in vestigial sideband (VSB) data transmission, with particular attention to the time required to recover carrier phase in order to achieve a satisfactory error rate. The acquisition is derived for simple models. The results are exhibited graphically relating pertinent system parameters. They indicate that while in double sideband transmission the acquisition time required to achieve a satisfactory error rate is of the order of a few symbol intervals, in VSB transmission this time grows to tens and hundreds of symbol intervals.

145. Meinel, A. B.
APPLIED OPTICS RESEARCH. Arizona Univ.,
Optical Sciences Center, Tucson, Arizona.
Annual rept. 1 Jul 1969-30 Jun 1970. Rept. no.
OSC-5223-970-140-3, Jul 1970, 56p. SAMSO TR-70-299. AD-876 593.

The report presents the results of the year's work, with particular emphasis on the activities of the past quarter, and statements of research and academic direction in the program areas that were supported entirely or in part by the contract. The dedication of the Optical Sciences Center building; lecturers and distinguished visitors; and seminars, colloquia, and lectures are discussed in Section I. Faculty additions, degree awards, student enrollment and 'Physics of Quantum Electronics' are discussed in Section II. Section III presents reports on the various fields of research in which progress was made during FY70. These are as follows: analog image processing, camera tube testing, electro-optical devices, glass physics, lens design and programming, mathematical optics, new materials, optical testing, quantum optics, structural mechanics, and thin films. Section IV gives a list of articles and reports written and/or published during the year.

146. Melchior, H., M. B. Fisher, and F. R. Arams
PHOTODETECTORS FOR OPTICAL COMMUNICATION SYSTEMS. Proceedings of the IEEE,
Vol. 58, No. 10, Oct 1970, pp. 1466-1486.

The characteristics of high-sensitivity photodetectors suitable for wide bandwidth optical communication systems are summarized. Photodiodes, photomultipliers, and photoconductive detectors for wavelengths from 0.3 μm to 10.6μ are covered. The use of

internal current gain by means of avalanche and electron multiplication and by means of optical heterodyne detection to increase sensitivity of high speed photodetectors is discussed. The application to visible and infrared laser communication systems is reviewed.

147. Milek, J. T. and S. J. Welles
LINEAR ELECTROOPTIC MODULATOR MATERIALS.
Hughes Aircraft Co., Electronic Properties Information Center, Culver City, Calif. Rept. no. EPIC-S-14, Jan 1970, 269p. Contract F33615-68-C-1225.
AD-704 556.

A comprehensive survey is presented of all important properties of 13 linear electro-optic materials: KDP, KDDP, KDA, ADP, KTN, lithium niobate, lithium tantalate, cuprous chloride, barium sodium niobate, prostite, calcium, pyroniobate and bismuth germanium oxide.

148. Milligan, F. G., R. L. Dobson, and G. M. Groome
LASER AIMING SIMULATION (LASIM). International Business Machines Corp., Federal Systems Div., Huntsville, Alabama. Final Report, Feb 1967 – May 1968. 20 May 1968, 191p. (Contract NAS8-21033). (NASA-CR-61975; IBM-68-K10-0006). N68-36166.

A detailed digital simulation is developed for the tracking and pointing performance of a spaceborne laser communications system experiment (LCSE) in synchronous earth orbit. Known as the laser aiming simulation (LASIM), the program is devoted to simulation of dynamics and control functions. Included are mathematical models of the orbital and rotational motion of the spacecraft, control moment gyroscopes, and the laser telescope. The control portion consists of the three tracking control systems and the point-ahead system. Capability for assessment of hardware imperfection effects on total system performance is provided. The mathematical formulations derived to depict the prototype hardware and system dynamics, from which the digital program was written, are presented. Analysis of LASIM data is presented in connection with assessing the ultimate feasibility of the LCSE operation.

149. Milne, G., J. Eyer, and C. Smoyer
EFFECTS OF SKY NOISE ON OPTICAL COMMUNICATION WITH SPACE VEHICLES. Institute of Optics, University of Rochester, New York. 9 Nov 1960, 44p. (Contract AF 30(602)1995). (RADC TR 61-149). AD-260 395.

Optical communication between ground stations and orbiting satellites or space vehicles will be influenced by the properties of the intervening atmosphere; any change in signal waveform introduced by the atmosphere can be regarded as sky noise. An extensive literature survey was undertaken to determine the magnitude and wavelength dependence of the various noise contributions. An experimental program revealed some aspects of scintillation.

150. Milton, A. F. and A. D. Schnitzler
DETECTION CONSIDERATIONS FOR LASER SYSTEMS IN THE NEAR INFRARED: PROGNOSIS FOR AN IMPROVED TECHNOLOGY. Institute for Defense Analyses, Science and Technology Div., Arlington, Va. Research Paper. Rept. no. RP-P-581 IDA/HQ-70-10983. Apr 1970, 58p. Contract DAHC15-67-C-0011. AD-707 317.

The paper summarizes the influence of detection considerations on the standard military optically pumped laser systems. The problems and uncertainties associated with the development of new photocathodes for the near infrared are discussed in detail. A variety of laser detection schemes are examined to determine their potential in the 1.5 micron to 2.5 micron region. The problems of imaging systems for use with laser illuminators are discussed. A research program is recommended to improve detector performance.

151. Minott, P. O., inventor (to NASA)
RETRODIRECTIVE OPTICAL SYSTEM. National Aeronautics and Space Administration, Goddard Space Flight Center, Greenbelt, Md. Issued 18 Mar 1969 (Filed 31 Oct 1966) 8p. Cl. 250-188. (NASA-Case-XGS-4480; U.S. Patent-3,433,960; U.S.-Patent-Appl-SN-591007). N69-27491.

An optical communication system is described which uses a remote retrodirective reflector modulator which is responsive to a remote information source. The modulator is a modified interferometer of the Fabrey-Perot type having non-planar surfaces. It is used in conjunction with a communications system in which an information carrying beam of light transmitted from a station on earth is relayed by a satellite to another station on earth. Inherent advantages of the laser communications system over a microwave system for use in space include higher transmission efficiencies and savings in the weight and size.

152. Modesitt, G.
THE MOLIERE APPROXIMATION FOR WAVE PROPAGATION IN TURBULENT MEDIA. Rand Corp., Santa Monica, Calif. Rept. no. RM-6325-ARPA, Sep 1970, 14p. Contract DAHC15-67-C-0141, ARPA Order-189-1. AD-712 456.

A solution is presented to the wave propagation equation obtained by direct analogy from a method commonly used to solve the Schrodinger equation for high-energy potential scattering. In optical communications and related devices, the random variations in the received signal due to atmospheric turbulence can represent a severe limitation to system performance. Studies of these fluctuations have been based on solutions to the wave propagation equation that are correct only to the first order in the refractive index deviation. This memorandum demonstrates a solution that is correct to all orders in the refractive index deviation and to lowest order in the stationary phase approximation. Although the solution is readily extended to next order in stationary phase, such an extension is recognized in scattering theory as unwarranted since it neglects terms of the same order from outside the region of stationary phase. The conventional Born and Rytov solutions in propagation theory are of questionable validity since they represent approximations to the extended solution.

153. Morrow, W. E. Jr.
SPACE COMMUNICATIONS, DIVISION 6.
Massachusetts Inst. of Tech., Lincoln Lab.,
Lexington, Mass. Quarterly technical summary
1 Jun – 31 Aug 1967. 15 Sep 1967, 36p. Contract
AF 19(628)-5167. ESD TR-67-496. AD-820 967.

This summary includes the work of all groups within Division 6. Communications, with the exception of the work on seismic discrimination in Groups 64 and 65, which is reported directly to the sponsor in a different form. It also reports on portions of the Space Communications Program undertaken by Division 3 (Radio Physics), Division 4 (Radar), and Division 7 (Engineering). LES-5 was successfully launched into orbit on 1 July 1967. It has been employed by tactical vehicles of the U.S. Army, Navy, Air Force, and NATO to demonstrate successfully the utility of tactical satellite communications. The Lincoln Laboratory-developed multiple-access Tactical Transmission System (TATS) was completed early in this quarterly period, and was installed in a small mobile terminal (LET-4). Successful tests using this new equipment at 75 and 2400 bps were made through LES-5. Construction of LES-6 is proceeding, but it now appears that the launch will be delayed until early summer 1968.

154. Michigan Univ., Inst. of Science and Technology,
Ann Arbor, Michigan.
PROCEEDINGS OF THE CONFERENCE ON LASER
TECHNOLOGY (4TH) HELD AT U.S. NAVAL TRAINING CENTER, SAN DIEGO, CALIFORNIA, 6–8 Jan
1970. VOLUME II. Rept. no. 2418-2-10-Vol. 2.
Mar 1970, 808p. Contract Nonr-1224 (52), ARPA
Order-306. AD-510 039L. (SECRET)

Original contains color plates; all DDC reproductions will be in black and white; see also Volume 1, AD-510 040L.

Distribution: DOD only; others to Chief, Office of Naval Research, Attn: Code 42p, Arlington, Va. 22217.

155. Michigan Univ., Inst. of Science and Technology, Ann Arbor, Michigan.
PROCEEDINGS OF THE CONFERENCE ON LASER TECHNOLOGY (4TH) HELD AT U.S. NAVAL TRAINING CENTER, SAN DIEGO, CALIFORNIA, 6–8 Jan 1970. VOLUME I. Rept. no. 2418-2-10-Vol. 1. Mar 1970, 902p. Contract Nonr-1224 (52), ARPA Order-306. AD-510 040L. (SECRET)

156. Montgomery, R. M.
EXPERIMENTAL EVALUATION OF ULTRAFAST PULSED LASER COMMUNICATION TECHNIQUES.
IEEE Journal of Quantum Electronics, Jun 1969, pp. 349–350.

A series of experiments have been carried out to evaluate the potential of mode-locked lasers for short-pulse optical communication. The laser used in these experiments was a He-Ne laser that produced 0.6-ns pulses at a 75-MHz rate. A crossed-field photomultiplier with a bandwidth of approximately 3 GHz was used as a detector, and a post detection gate having a 1-ns width and 75-MHz repetition frequency was developed for this program.

157. Moreau, R.
APPLICATION OF LASERS TO LOCATING SPACECRAFT (APPLICATION DES LASERS A LA LOCALISATION D'UN MOBILE DANS L'ESPACE). L'Aeronautique et l'Astronautique, Vol. 14, no. 7, 1969, pp. 59–64, 5 refs. In French.

Description of two laser-based devices; one, equipped with a Q-switched laser, for accurate range measurements, while the other, with a high energy per pulse, permits a satellite carrying cube corners to be photographed by night against a background of stars, up to a distance of 3000 km. These two pieces of equipment help to ensure accurate location (to within a few meters from a single station). A study is made of detection optimization in the presence of noise.

158. Moreau, R. and P. Weber
LASER RANGE-FINDING AT THE LANDES TEST-CENTER (TELEMETRIE LASER AU CENTRE D'ESSAIS DES LANDES). La Recherche Aérospatiale, Sep – Oct 1969, pp. 50,51. 5 refs. In French.

Description of a mobile missile ranging station using a laser providing an energy of 1 J in 30 nsec. The station is compared with an installation used for telemetry of geodesic satellites, and differences between the two stations are discussed.

159. Moss, E. B.
INFLUENCE OF IR FREQUENCIES ON TRACKING FOR OPTICAL COMMUNICATION. IN: American Astronautical Society, Southeastern Symposium on Missiles and Aerospace Vehicles Sciences, Huntsville, Alabama, December 5–7, 1966, Proceedings. Volume 1. Symposium sponsored by the American Astronautical Society, the University of Alabama, NASA Marshall Space Flight Center, and the Missile Command of the U.S. Army. Huntsville, Ala., American Astronautical Society, Southeast Section, 1966, pp. 38-1 to 38-12. 10 refs.

Discussion of beam formation for optical communication between earth and interplanetary spacecraft and examination of the tracking problem, detectors, and their characteristics. It is pointed out that the microscopic dimensions of semiconductor wideband detectors, rather than beamwidth, will determine tracking requirements for cooperative optical communication at the present state of detector technology. It is noted that means of increasing the effective area of detection without prejudice to performance need investigation. This investigation should explore optical and electronic approaches, as well as fundamental research in solid-state detector technology.

160. Moss, E. B.
SOME ASPECTS OF THE POINTING PROBLEM FOR OPTICAL COMMUNICATION IN SPACE. American Institute of Aeronautics and Astronautics, Annual Meeting, 1st, Washington, D.C., Jun 29 – Jul 2, 1964, Paper 64-420. 11p.

Demonstration that the ability to direct an extremely narrow beam at a target receiving station, in order to illuminate it, may be a critical factor in the feasibility of laser communication in space. The demonstration is based on an examination of the situations arising during a typical space mission assumed to depend solely on a laser channel for two-way communication. The channel would have the maximum bandwidth from space to Earth, and a command and data link of lesser bandwidth from Earth to the space vehicle. The mission chosen as the basis of discussion is an Earth-to-Venus probe in a favorable period, and, following the maximum payload trajectory, a voyage lasting over 100 days. Effects of the Earth's atmosphere on communications are delineated and aspects of acquisition, tracking, and beam pointing are analyzed in detail. The study shows that optical communication at high information rates over interplanetary distances will be infeasible until optical bandwidths can be brought close to information bandwidths. Until then, both communication and tracking will be prejudiced by noise arising from extraneous sources of illumination. Attempts to avoid these will greatly restrict system design. The development of linear, preferably solid-state, beam deflectors is considered essential to the future use of optical communications in space.

161. Moss, E. B.
SYSTEMS PROBLEMS IN THE USE OF LASERS IN SPACE COMMUNICATION. IN: Electronics in Transition; Winter Convention on Military Electronics, 6th, Los Angeles, Calif., February 3–5, 1965, Proceedings. Volume 4. (A65-23182 13-09). Conference sponsored by the Professional Technical Group on Military Electronics of the Institute of Electrical and Electronics Engineers, Los Angeles Section. Los Angeles, Institute of Electrical and Electronics Engineers, Los Angeles District, 1965, pp. IIIB-26 to IIIB-39. 17 refs.

Examination of problems involved in the use of lasers in space communication. The relative merits of microwave and optical systems are analyzed. The problem of

coherence is discussed in its connection with narrow beam formation and with the possibility of frequency modulation of the carrier. Problems connected with the receiver optics and beam deflection are considered. Tracking, beam pointing, and acquisition are studied in some detail. Various atmospheric effects are taken into account. It is concluded that the application of the laser to space communication awaits further advances primarily in the field of laser technology. Until such advances are made, it is said that optical communication cannot replace uhf, since the reliability of a microbeam optical link is too low for total reliance to be placed on it. The ultimate role of optical communication in space is seen to be as a medium for the mass transfer of qualitative information rather than as a substitute for conventional telemetry.

162. Nagel, M. R.
PROBLEMS AND PROGRAMS ON THE USE OF SUBMILLIMETER WAVES IN SPACE. National Aeronautics and Space Administration, Electronics Research Center, Cambridge, Mass. Washington 1968, 49p. (NASA-SP-182). N68-35522.

The development and the present status of the technology associated with the use of submillimeter waves in field and space applications are described. A compilation of tables, graphs, and other data on the performance of modern submillimeter components is given, along with a list of the most recent literature on the subject. Some of the more significant achievements and the potential of submillimeter waves in the atmospheric and astronomical disciplines and in spaceflight-related operations, are discussed. A review of related programs currently sponsored by the National Aeronautics and Space Administration is given and high priority research needs that may lead to a more effective utilization of submillimeter radiation in space are pointed out.

163. National Aeronautics and Space Administration, Lewis Research Center, Cleveland, Ohio.
SPACE TRANSPORTATION SYSTEM TECHNOLOGY SYMPOSIUM. VOLUME 6: INTEGRATED ELECTRONICS (INCLUDING ELECTRIC POWER). Symposium held at Cleveland, 15–17 Jul 1970. Jul 1970, 376p. (NASA-TM-X-52876-Vol. 6; E-5866, Vol. 6). N70-40951.

Research and development of electronic equipment for space shuttle vehicles is discussed, including integration of avionics systems, onboard data processing and

management, terminal navigation and guidance, laser and solid state communication devices computerized imaging techniques for approach and landing control, and electric power systems. For individual titles see N70-20952 through N70-40975. For volume 1 see N70-37826 through N70-37847, for volume 2 see N70-36595 through N70-36615, for volume 4 see N70-39626 through N70-39637, and for volume 5 see N70-39603 through N70-39616.

164. National Aeronautics and Space Administration, Marshall Space Flight Center, Huntsville, Ala. PROCEEDINGS OF THE SPACE OPTICAL TECHNOLOGY CONFERENCE, VOLUME 1. Conference held 2--4 Nov 1965. Apr 1966, 156p. (NASA-TM-X-61037). N68-31759.

CONTENTS:

1. Participation of Ames Research Center in The MSC-4 Experiment, N. S. Johnson (NASA. Ames Res. Center) pp. 1−7 (See N68-31760-19-16).
2. Radot. 60.96-CM(24-IN). Multimode Telescope and Future Facilities, W. J. Carrion (NASA, Goddard Space Flight Center) pp. 9−15 (See N68-31761-19-07).
3. Analysis of a Ten-Micron Communication System, N. McAvoy (NASA, Goddard Space Flight Center), pp. 17−31 refs (See N68-31762-19-07).
4. Spherical Miros, P. O. Minott (NASA, Goddard Space Flight Center), pp. 33−41, (See N68-31763-19-07).
5. The Optical Imaging Systems for Ranger, Mariner, and Surveyor Television, E. P. Martz, Jr. (JPL) pp. 43−50 (See N68-31764-19-14).
6. Advanced Computer Design Techniques for Optical Systems, J. M. McLauchlan (JPL), pp. 51−57 (See N68-31765-19-08).
7. Feasibility Studies of Optical Space Communications and Tracking, and other Activities of the JPL Quantum Electronics Group, W. H. Wells (JPL) pp. 59−65, refs (See N68-31766-19-07).
8. Technology for a Manned Orbiting Telescope, W. E. Howell (NASA, Langley Res. Center), pp. 67−80, (See N68-31767-19-14).
9. Optical Communications Experiments on Gemini VII, D. S. Lilly (NASA, Manned Spacecraft Center), pp. 81−90, (See N68-31768-19-07).
10. Manned Spacecraft Center Laser Programs and Plans, W. L. Thompson (NASA, Manned Spacecraft Center), pp. 91−97 (See N68-31769-19-16).
11. White Sands Missile Range Station for MSC-4, R. W. Ward (NASA, Manned Spacecraft Center, pp. 99−102 (See N68-31770-19-07).
12. The Optical Guidance System for Rendezvous, C. L. Wyman, pp. 103−114 refs (See N68-31771-19-21).
13. Optical Technology Experiments for Apollo Applications Program, E. J. Reinbolt and J. L. Randall, pp. 115−129 (See N68-31772-19-07).
14. Some Astrophysical Instrumentation Considerations Related to Space Optical Technology, G. A. Vacca (NASA, Headquarters), pp. 131−142 (See N68-31773-19-14).

165. Naval Missile Center, Point Mugu, Calif.
INDEPENDENT RESEARCH PROGRAM
FISCAL YEAR 1970. Annual rept. Rept.
no. NMC-TP-70-66, 1 Oct 1970, 53p. AD-
511 218L. (CONF.)

166. Nomura, S. and Y. Hasegawa
MODULATION AND DEMODULATION OF He-Ne
LAS.R LIGHT AT 7 GHz MICROWAVE FREQUENCY.
Japan, J. Appl. Phys. 6(1967)651.

The light communication using Pockels modulator has been studied by several authors. In this note television pictures were transmitted over a gas laser light beam with an ADP crystal at 7 GHz modulating frequency.

For the autostabilization of the power to the modulator at the microwave frequency, the ADP crystal has a suitable temperature dependence of dielectric constant and loss tangent along the c-axis in the microwave region, though the electrooptic coefficient of ADP is smaller than KDP. From this reason the ADP crystal was selected as the modulator material. In order to apply voltages to the crystal, the modulator operating at 7 GHz was designed using the similar technique as proposed by Blumenthal. A reentrant capacity-loaded resonator was employed and the quality factor Q of the modulator was measured to be about 200 at 7 GHz. The ADP crystal was mounted so that the electric field and optical path through it were parallel to its c-axis.

167. North American Aviation, Inc., Space and
Information Systems Div., Los Angeles, Calif.
EXPERIMENTAL LASER SPACE COMMUNICA-
TIONS PROGRAM. TASK 1: PROBLEM DEFINI-
TION, VOLUME II. 9 Oct 1964, 320p. N64-32756.

CONTENTS:

VOLUME II

1. Atmospheric Turbulence and its Effect on Laser Communications Systems: Second Report, D. L. Fried and J. D. Cloud, pp. 1-73 refs (See N64-32757-24-08).
2. The Relationship Between Random Optical Wave Front Distortion and Optical System Performance, D. L. Fried, pp. 74-134 (See N64-32759-24-08).

3. Optical Heterodyne Detection of an Atmospherically Distorted Signal Wave Front, D. L. Fried, pp. 135–170 refs (See N64-32759-24-08).
4. The Statistics of Geometrical Interpretation of Wave Front Deformation, D. L. Fried and J. D. Cloud, pp. 171–184 refs (See N64-32760-24-08).
5. The Significance of the Inner Scale of Turbulence to the Phase Structure Function, J. D. Cloud and D. L. Fried, pp. 185–194 (See N64-32761-24-08).
6. Extension of Results for Phase and Log Amplitude Correlation: Higher-Order Terms in the Near-Field Series and Coverage of the Far-Field, D. L. Fried and M. F. Sternberg, pp. 195–224 (See N64-32762-24-08).
7. Further Evaluation of Phase and Amplitude Correlation Functions for an Atmospherically Distorted Wave Front, J. D. Cloud, pp. 225–266 (see N64-32763-24-08).
8. The Angular Scintillation Correlation Function, D. L. Fried, pp. 267–287 refs (See N64-32764-24-08).
9. RMS Angular Resolution by the Wave Front Approximation Technique, D. L. Fried, pp. 288–294 refs (See N64-32765-24-08).
10. Atmospheric Optical Doppler: An Approximate Evaluation, D. L. Fried, pp. 295–306 refs (See N64-32766-24-08).

168. Nugent, L. J., and R. J. Condon
VELOCITY ABERRATION AND ATMOSPHERIC REFRACTION IN SATELLITE LASER COMMUNICATION EXPERIMENTS. Applied Optics, vol. 5, Nov 1966, pp. 1832–1837. 8 refs.

The effects of satellite velocity aberration and atmospheric refraction on the direction of propagation of laser radiation reflected from a satellite back to an observer on the earth are examined. A velocity aberration analysis for the two-dimensional case where the satellite passes directly overhead at velocity v is presented to first order in v/c in order to illustrate the method. The equations for the more general three-dimensional case are then given to first order in v/c, and it is indicated that higher order treatments are normally unnecessary in typical experimental considerations. Following this, a simple approximate equation giving the atmospheric refraction to an accuracy of a few microradians is developed, it is indicated that greater accuracy is not important because of laser pointing limitations imposed by atmospheric scattering and turbulence. The atmospheric refraction equation depends only on the apparent zenith angle of the satellite reflector relative to the earth-based laser, on the satellite altitude, and on the index of refraction of the laser radiation in the atmosphere at the earth's surface. Both of these developments should be useful in the design and interpretation of satellite laser-communication experiments.

169. Office of Naval Research, Boston, Mass.
PROCEEDINGS OF THE CONFERENCE ON LASER TECHNOLOGY (4TH), HELD AT U. S. NAVAL TRAINING CENTER, SAN DIEGO, CALIFORNIA 6-8 JANUARY 1970. VOLUME III. 8 Jan 1970, 104p. Contract ARPA Order-306. AD-511 257L. (CONF.)

170. Office of Naval Research, Boston, Mass.
PROCEEDINGS OF THE CONFERENCE ON LASER TECHNOLOGY (4TH), HELD AT U. S. NAVAL TRAINING CENTER, SAN DIEGO, CALIFORNIA, 6-8 JANURAY 1970. VOLUME 4. Nov 1970, 493p. Contract ARPA Order-306. AD-512 984L. (SECRET)

171. Office of the Director of Defense Research and Engineering, Advisory Group on Electron Devices, Washington, D. C.
ADVANCED ELECTRON DEVICE TECHNOLOGY. Status rept. no. 119, Oct 1970, 63p. AD-875 944.

Contents: Microwave devices; Optical masers; Special devices; Low power devices; High power devices; and Passive devices.

172. Ohio State Univ., Electroscience Lab., Columbus, Ohio.
LASER PROPAGATION INVESTIGATIONS. Final technical rept. 1 Jan 1967-31 May 1969. Rept. no. 2384-8, 10 Oct 1969, 19p. Contract F33615-67-C-1299. AFAL TR-69-261. AD-861 172.

This report describes an interferometer for infrared atmospheric turbulence studies and its use at 10.6 micrometers. The absorption of CO_2 laser energy by atmospheric H_2O and CO_2 is described in a quantitative manner including high altitude and slant

path situations. Reduction of absorption using an isotope CO_2 laser is described. Extensive calculations and measurements of forward extinction by aersols, rain, and fog are mentioned as well as calculations and measurements of backscattered energy.

173. Ohlmann, R. C.
COMPONENT CHARACTERISTICS FOR A WIDE-BAND FM/IM OPTICAL DATA RELAY SYSTEM.
Fourth Conference on Laser Technology, San Digeo, Jan 1970, p. 1401.

Describes components and system results for a 500-MHz bandwidth laser communications system.

174. Packard, R. D.
MERCURY CADMIUM TELLURIDE AS A 1- TO 20-MICROMETER WAVELENGTH INFRARED DETECTOR FOR SPACE APPLICATIONS. Nationa Aeronautics and Space Administration, Electronics Research Center, Cambridge, Mass. Nov 1968, 17p. (NASA-TN-D-4904). N69-10125.

Mercury cadmium telluride (HgCdTe) offers attractive possibilities for fast, elevated operating temperature infrared detection from 1- to 20-micrometer (μm) wavelengths, particularly in the 8- to 14-μm wavelength region for which it was developed HgCdTe is considered for use in satellites for terrestrial, atmospheric, and ocean mapping; infrared astronomy; and optical communications. Its chemical stability in the space environment is open to some question; however, experimental data so far accumulated indicate that it is marginally adequate for such purposes. Some attention is given to the possibility of operation using (passive) space radiative cooling; this would eliminate the need for cryogens and provide a much longer operating lifetime as well as reductions in size and weight of the detector system.

175. Paoli, T. L. and J. E. Ripper
DIRECT MODULATION OF SEMICONDUCTOR LASERS. Proceedings of the IEEE, vol. 58, No. 10, Oct 1970, pp. 1457–1465.

Methods for direct modulation of semiconductor lasers are reviewed with the objective of indicating the advantages and limitations of each method. Techniques for producing amplitude, pulse, and frequency modulation of the optical wave are included. The modulation capabilities of present pulsed lasers are analyzed with special attention given to their operation at room temperature. In addition, several ways of producing analog position or width modulation of microwave-rate optical pulses are described and the capabilities of optical frequency modulation by acoustic waves are reviewed. A new way of obtaining mode-locked optical pulses with a semiconductor laser is also suggested.

176. Park, E. C. and L. S. Stokes
Hughes Aircraft Co., Culver City, Calif.
LASERS VS MICROWAVES FOR DEEP-SPACE COMMUNICATIONS. Microwaves, vol. 6, May 1967, pp. 78–90, 20 refs. Contract No. NAS 12-81.

Comparison of microwaves and laser links for spacecraft-to-earth communications, and description of a hybrid system combining the best features of lasers and microwaves. Significant restrictions on communication-system performance are due to external noise sources and atmospheric effects, which identify certain favorable regions of the spectrum, and to engineering and technological limitations on aperture gain, which determine the achievable levels of performance within these favorable regions. Distortions of the incident wavefront caused by atmospheric turbulence limit the effective dimensions. Fabrication tolerances set gain limits to both received and transmitted apertures. Gain is finally limited at the high-frequency end of the spectrum by the need for a beamwidth comparable to expected pointing errors.

177. Perkin-Elmer Corp., Norwalk, Conn.
OPTICAL TECHNOLOGY APOLLO EXTENSION SYSTEM (OTES), VOLUME 1. Oct 1967, 504p. (Contract NAS8-20255). (NASA-CR-90530; Rept. 8900, v. 1). N68-11864.

A number of optical technology space experiments are identified, studied, and described in detail. Five different system concepts (vidicon imaging system, spectrometer, laser, optical telescope, and spectrograph) were evolved and examined for

feasibility within the restraints and guidelines of the specification. Optical communications, and ground station requirements for the Optical Technology Apollo Extension System (OTES) are also described.

178. Perlman, B. S. and C. L. Upadhyayula
TRANSFERRED ELECTRON AMPS CHALLENGE THE TWT. Microwaves, vol. 9, Dec 1970, pp. 59, 60, 62, 64. 12 refs.

Discussion of the possibility of application of transferred electron amplifiers (TEA) to airborne electronic countermeasures (ECM) systems. It is shown that TEA offers the possibility of several octaves of available bandwidth from C through Ku band for CW power levels of several watts. In addition, linear amplifier gain over a dynamic range as large as 90 dB with instantaneous bandwidths of 3 to 4 GHz and typical noise figures of 15 dB are possible. This qualifies the TEA for use in ECM memory systems that must respond to hostile radar signals by retransmitting a reasonable replica of the received pulse. A comparison of the TEA with low noise traveling wave tubes used so far in ECM systems for this purpose is presented.

179. Personick, S. D.
EFFICIENT ANALOG COMMUNICATION OVER QUANTUM CHANNELS. Massachusetts Inst. of Tech. Cambridge Research Lab. of Electronics, Cambridge, Mass. Technical rept. Rept. no. TR-477. 8 Jan 1970, 112p. Contract DA-28-043-AMC-02536(E). AD-707 948.

The report is concerned with the incorporation of the axioms of quantum measurements into current communication estimation theory. It is well known that classical electromagnetic theory does not adequately describe fields at optical frequencies. The advent of the laser has made the use of optical carriers for information transmission practical. Classical communication estimation theory emphasizes background noise and channel fading as primary limitations on system performance. At optical frequencies, quantum effects may totally dominate performance. Estimation theory is formulated using the quantum theory so that this type of system limitation can be understood and optimal receivers and systems designed.

180. Peters, W. N. and R. J. Arguello
FADING AND POLARIZATION NOISE OF A PCM/PL SYSTEM. IEEE Journal of Quantum Electronics, vol. QE-3, No. 11, Nov 1967, pp. 532-539.

This paper presents a generalized mathematical model of a PCM/PL system. The analysis demonstrates that any two orthogonal polarizations may be used to represent the binary bits. The generalized approach also facilitates the derivation of the system bit error rate when polarization errors are introduced. Six types of polarization errors are assumed for the discussion. The various cases of polarization errors are presented as operations on the Poincare sphere. These operations are then formalized in terms of the Mueller Matrix theory. The matrix algebra permits the derivation of the bit error-rate curves for the six polarization error cases. Assuming that the atmospheric-induced fading is log normally distributed, the bit error rate for a PCM/PL fading channel is computed.

181. Philco-Ford Corp., Western Development Labs., Palo Alto, Calif.
OPTIMIZATION OF USER AND EARTH STATION INTERFACES WITH DSCS. TASK 1. MULTIPLE CARRIER WIDEBAND TRANSMISSION AND RECEPTION. Final rept. on HT and MT. Rept. no. WDL-TR3879, 29 Apr 1969, 320p. Contract DAAB07-68-C-0351. Includes Revision dated Oct 1969. AD-505 456. (SECRET)

This Task 1, Multiple Carrier Wideband Transmission and Reception, report summarizes the work performed in defining HT (heavy terminal) and MT (medium terminal) function design configurations.

182. Plotkin, H. H.
OPTICAL TECHNOLOGY FOR EXPERIMENTS AND APPLICATIONS IN CISLUNAR SPACE. National Aeronautics and Space Administration, Goddard Space Flight Center, Greenbelt, Md. Presented at the NASA/EIA Briefing on Aerospace Electron. Systems Technol. Cambridge, Mass., 3-4 May 1967. 1967, 25p. (NASA-TM-X-59786). N68-34676.

Discussed is the application of tracking satellites with pulsed and continuous lasers for studies of atmospheric properties and experiments in optical space communications. A pulsed ruby laser radar system on the satellite, boresighted with the camera, can determine its altitude above the earth surface with a precision of two meters. Pulsed laser ranging can also be used for precise measurements of the moon's motion. Large orbiting telescopes will give excellent optical performance since the degrading

atmospheric effects are absent; a 3-meter diameter astronomical telescope in orbit would have an angular size image (at 5000 Å) of 4 ± 10^{-7} radians, or 0.08 seconds of arc.

183. Plotkin, H. H.
THE S-66 LASER TRACKING EXPERIMENT.
National Aeronautics and Space Administration,
Goddard Space Flight Center, Greenbelt, Md.
IN: Its Publ. of Goddard Space Flight Center,
1963, Vol. II (1963), pp. 880–884. N66-32076.

Presented are numerical calculations for an optical satellite tracking experiment that uses Q-switched rubidium laser signals to illuminate special reflectors attached to satellites, receives the reflected light, measures the time of flight for range, and autotracks the reflected pulse to obtain angle coordination as well. Numerical estimates of expected signal reflections show that a pulse of 1 joule from a ruby laser, attenuated to 0.8 in each passage through the atmosphere, is reflected by a 2000 cm^2 mosaic array of small retroreflectors at a range of 1500 km, within a cone of 10^{-4} radian diameter, and can be received in a telescope aperture area of about 500 cm^2.

184. Plotkin, H. H.
TRACKING OF THE BEACON-EXPLORER
SATELLITES WITH LASER BEAMS. National
Aeronautics and Space Administration, Goddard
Space Flight Center, Greenbelt, Md. 1965, 4p.
(NASA-TM-X-56631). N66-22191.

The value of using lasers for accurate tracking of orbiting optical reflectors is assessed. Results of optical tracking experiments with the Beacon Explorer satellites indicate that precise measurements of satellite positions may be determined. Present optical tracking methods require photography by reflected sunlight at a time when the sky is dark enough to permit simultaneous photography of the stars. However, it is observed that studies are being conducted to permit laser range determinations during daylight and when the satellite is in the shadow of the earth.

185. Potter, P. D., M. S. Shumate, and C. T. Steizried
A STUDY OF WEATHER-DEPENDENT DATA LINKS FOR DEEP SPACE APPLICATIONS. Jet Propulsion Lab., Calif. Inst. of Tech., Telecommunications Div., Pasadena, Calif. 15 Oct 1969, 44p. (Contract NAS7-100). N70-11738.

The information data rate of deep space communication links used for spacecraft-to-earth purposes is always severely limited by the size and power capacity of the spacecraft itself. Present deep space communication links, utilizing S band frequencies, have been improved to so high an efficiency that the information data rates obtainable cannot be increased significantly without attendant increases in spacecraft size. One solution to the problem of obtaining higher data rates is to operate the data link at frequencies higher than S-band. This report considers the operation of a reliable deep space communication link at such frequencies in the presence of weather disturbances, and presents a comparison of five potential systems; two microwave (X-band and mm-band) and three laser bands (10 micrometers, 4 micrometers and near visible). The advantages and disadvantages of each of these systems are discussed, and recommendations for future work in these areas are presented.

186. Prabhu, V. K.
ON THE PROBLEM OF BROADBAND SIGNAL AND NOISE PERFORMANCE OF DIRECT DETECTION OPTICAL RECEIVERS. Applied Optics, Vol. 7, No. 12, Dec 1968, p. 2401.

A theory of broadband signal and noise performance of a direct detection optical receiver is presented in this paper. Explicit expressions are given for the gain and noise factor of the optical receiver, consisting of a photodiode followed by a high gain, low noise baseband amplifier. It is assumed that a linear lumped lossless interstage network is placed between the diode and the amplifier to obtain broadband performance from the optical receiver. The constraints imposed by the photodiode on the wide-band characteristics of the gain G_R and noise factor F_R of the optical receiver are obtained in integral and nonintegral forms.

187. Pratt, W. K. and R. J. Norton
RADIO FREQUENCY SUBCARRIER, DIRECT DETECTION, INTENSITY MODULATION, LASER COMMUNICATION SYSTEMS. University of Southern California, Dept. of Electrical Engineering, Los Angeles, Calif. Rept. no. USCEE-226, Jun 1968, 32p. Contract F04701-68-C-0234, F04695-67-C-0109. SAMSO TR-68-180. AD-835 643.

Information transmission on a radio frequency subcarrier over an intensity modulated optical carrier, rather than direct intensity modulation of the carrier, offers some implementation advantages, immunity to certain types of noise, and a convenient information multiplexing capability. However, there is a penalty paid in reduced signal-to-noise ratio and an increased probability of detection error.

188. Putz, J. L.
A WIDE-BAND MICROWAVE LIGHT MODULATOR. Transactions on Electron Devices, Vol. ED-15, No. 10, Oct 1968, pp. 695–698.

An experimental potassium dihydrogen phosphate (KDP) light modulator with a 10 percent (half-m) bandwidth at 6 GHz is described. When arranged for amplitude modulation, a modulation depth of 40 percent was obtained with 10 watts of input power at band center. With a different optical arrangement, phase modulation is also possible.

The modulator uses a ring-plane traveling-wave circuit with cylindrical KDP crystals filling the space inside the rings. The crystals are used in the longitudinal mode, i.e., with the light along the optic axis, thus avoiding some of the thermal problems associated with transverse node operation. The circuit provides adequate cooling for the crystals and CW or pulsed operation at average RF levels of 10 watts is possible. Measurements indicate that the limitation in bandwidth is due mainly to the dispersion of the circuit and that with suitable modifications bandwidths of 20 percent are quite feasible.

189. Randall, J. L.
ATMOSPHERIC EFFECTS ON OPTICAL COMMUNICATION SYSTEMS. IN: Laser applications in the geosciences: Douglas Advanced Research Laboratories, Symposium, Huntington Beach, Calif., Jun 30–Jul 2 1969, Proceedings. Edited by J. Gauger and F. F. Hall, Jr. North Hollywood, Calif., Western Periodicals Co., 1970, pp. 81–95. 14 refs.

Survey of results on atmospheric effects as they relate to the practical effects on an optical communication link or other laser applications in the geosciences giving particular attention to turbulence effects. The principles of operation of optical communication systems are briefly discussed. The atmospheric effects considered are related to attenuation through scattering, amplitude scintillation, phase scintillations, beam spreading, frequency spreading and path length fluctuations.

190. Randall, J. L.
OPTICAL COMMUNICATIONS FROM DEEP SPACE. National Aeronautics and Space Administration, Marshall Space Flight Center, Huntsville, Ala. IN: Its Aerospace Electron. Systems Technol. 1967, pp. 179–187. N63-33181.

The problems associated with optical communication are identified as (1) pointing of the very narrow fractions of an arc (second) optical beams to insure interception by the receiver in the presence of point-ahead requirements caused by velocity aberration; (2) acquisition and tracking of the intercepted beam by the receiver; (3) atmospheric disturbances; (4) electrical efficiencies of the lasers and modulators; and (5) maintenance of diffraction-limited optics or antennas. Pointing system configurations under study are the open-loop, cooperative, and closed-loop systems; probably a cooperative system or the closed-loop system with possibly a combination system will be used. The basic concept the two-way optical communication link is discussed and depicted. Examples are given to show the data rates attainable with optical systems: in the visible region incoherent detection is superior to coherent detection, while coherent detection is superior at 10.6 μ. Optical and radio frequency systems are compared with respect to those factors affecting the efficiency of utilization of primary energy. Required technology advances are indicated.

191. Randall, J. L.
OPTICAL TECHNOLOGY PROGRAM. National Aeronautics and Space Administration, Marshall Space Flight Center, Huntsville, Ala. IN: Its Electron. Res. at MSFC 1965, pp. 1–10. N66-23457.

Details are given on optical and infrared technology research directed toward developing advanced optical systems for guidance, tracking, and communication in aerospace missions. Component and device studies center on laser sources, detectors, modulators, beam scanners, and ring lasers. Communication and tracking techniques, involving superheterodyne receiver and frequency stabilization, are also being developed for use in particular systems. Theoretical and experimental studies on atmospheric effects in optical tracking and communication are reported, and progress on optical design, fabrication, and evaluation of components is outlined. The objectives of the optical technology satellite program are summarized, and a tentative list of the experiments chosen to simulate deep-space communication for ranges up to 160 million kilometers is included.

192. Rattman, W. J., W. E. Bicknell, and B. K. Yap
BROADBAND, LOW DRIVE-POWER ELECTRO-OPTIC MODULATOR. IEEE Journal of Quantum Electronics, Vol. QE-3, No. 11, Nov 1967, p. 550.

A compact optical intensity modulator has been constructed and tested which operates at 6328 Å and requires 60 mW of drive power per MHz of operating bandwidth. Intensity modulation of 100 percent was achieved with a transistorized driver delivering 6 watts over a 100-kHz to 100-MHz bandwidth. The low drive-power performance is obtained by using a KD*P crystal modulator cell having a large length to cross-section ratio and laser beam condensing optics. This paper treats the design of the optical modulator and the results of tests performed over the 100-MHz bandwidth.

193. Rattman, W. J., B. K. Yap, and W. E. Bicknell
WIDEBAND HIGH EFFICIENCY OPTICAL MODULATOR. Sylvania Electric Products, Inc., Applied Research Lab., Waltham, Mass. Final Report, 15 Feb 1966–15 Mar 1967. 15 Mar 1967, 54p. (Contract NAS8-20545) (NASA-CR-82929). N67-19932.

A project to develop two 100-MHz bandwidth electro-optic modulators and solid-state drivers which achieve 100 percent amplitude modulation with less than 10 watts modulator drive power is discussed. This report treats the design of this optical modulation system and the results of tests performed over the full 100-MHz bandwidth.

194. Reinbolt, E. J. and J. L. Randall
HOW GOOD ARE LASERS FOR DEEP-SPACE COMMUNICATIONS? Astronautics and Aeronautics, vol. 4, Apr 1967, pp. 64–70. 9 refs.

Study showing that optical systems are promising, particularly when combined with rf techniques, for the relaization of high-information-rate deep-space communication systems. The great potential of optical frequencies for the transmission of high data rates from deep space to earth resides mainly in the very tight optical beam, or high antenna gain. It is pointed out that rf communications systems have been developed to a very advanced technology, and that the only way to improve the data-rate capability of these systems from deep space is to increase transmitter power or to increase the size of the transmitter and receiver antennas, which are already approaching practical limits. On the other hand, optical, and IR communication systems have room for improvement with increased laser efficiency, better detectors and modulators, and a reasonable increase in antenna size and transmitter power output.

195. Reno, C. W.
SOLAR-PUMPED MODULATED LASER. Radio Corp. of America, Camden, N. J. IN: NASA Marshall Space Flight Center Space Opt. Technol. Conf., Vol. 2, Apr 1966, pp. 143–154. (Contract NAS9-3671). X68-18191.

NOTICE: Available to U.S. Government Agencies and Their Contractors Only.

The assembly, operational characteristics, and advantages of a solar pumped modulated laser for communications are discussed. Three laser materials, $CaF_2:Dy^{2+}$, $YAG:Nd^{3+}$, and $YAG:Nd^{3+}$ were evaluated because of their relatively broad absorption bands. The characteristics of these materials are discussed and the pumping mechanisms and applications of each material are outlined. The major components of the optical communications system are shown, and preliminary performance characteristics are discussed. It is reported that solar pumped modulated lasers can operate effeciently and that modulation bandwidths in excess of 6 MHz can be realized.

196. Replogie, F., C. Barrow, and J. Spalding
OPTICAL PROPAGATION STUDY. Perkin-Elmer Corp., Electro-Optical Div., Norwalk, Conn. Final rept. Rept. no. PE-8041, Jan 1966, 338p. Contract AF 30(602)-3685. RADC TR-65-511. AD-476 244.

This report is intended to be an introduction and a guide for individuals conducting optical propagation measurements. After developing the meteorological and optical theory it gives specifications and details on a transportable ground-based optical propagation measurement facility. When the specified equipment and appropriate meteorological measuring equipment are used at sites having a geometrically simple terrain, the results obtained should permit the optical and meteorological theories to be verified and extended.

197. Reynolds, R. S.
STABILIZED CARBON DIOXIDE GAS LASER. Sylvania Electric Products, Inc., Mountain View, Calif. Final Report, 1 Dec 1966– 30 Jan 1968. 30 Jan 1968, 78p. (Contract NAS5-10309) (NASA-CR-95055). N68-25723.

A CO_2 laser capable of high power at a single frequency, highly stabilized on the short term is presented. This laser has been developed for use in long range communications systems. The laser utilizes a master-oscillator, power-amplifier to achieve high power simultaneously with high stability and is capable of providing up to 38 watts of single-frequency light in the TEM_{00q} mode. A temperature-controlled oscillator provides 5 watts of power at a single wavelength at 10.6 microns for an active plasma length of 50 cm. A second oscillator was used to obtain relative frequency stability information by heterodyne techniques. Long-term stability, as determined by the thermal environment was about ±3 parts of 10^7. The short-term stability varied

between 5 parts in 10^{11} and 1 part in 10^{9} over a 10 ms time interval. The short-term frequency stability depends strongly on the laser acoustical environment. Experimental results are also presented on the effects of RF excitation, laser bore size and gas mixture on the laser output.

198. Riesz, R. P. and M. R. Biazzo
GIGAHERTZ OPTICAL MODULATION. Applied Optics, Vol. 8, No. 7, Jul 1969, pp. 1393–1396.

Light pulses from a mode-locked He-Ne laser have been modulated by a $LiTaO_2$ electrooptic crystal mounted on a thin film substrate. The crystal was driven by pulses from a GaAs Gunn effect diode. Amplitude modulation of 20% has been achieved at 2 GHz for a single pass through the modulator.

199. Ripper J. E.
ANALYSIS OF FREQUENCY MODULATION OF JUNCTION LASERS BY ULTRASONIC WAVES.
IEEE Journal of Quantum Electronics, Vol. QE-6, No. 2, Feb 1970, pp. 129–132.

An analysis of the interaction of ultrasonic waves with the junction-laser modes is performed, using first-order perturbation theory. It demonstrates that in the presence of sound waves, each laser mode is frequency-modulated with negligible harmonic distortion or mode mixing. It is also shown that bandwidths of several GHz, with high-modulation index are possible.

200. Ripper, J. E., G. W. Pratt, Jr., and C. G. Whitney
DIRECT FREQUENCY MODULATION OF A SEMICONDUCTOR LASER BY ULTRASONIC WAVES.
IEEE Journal of Quantum Electronics, Vol. QE-2, No. 9, Sep 1966, pp. 603–605.

A discussion is given of frequency modulation of a semiconductor laser using ultrasonic waves. The principle used is the modulation of the dielectric constant of the material by the ground waves. This modulates the laser output due to the refractive index dependence of the mode frequencies. It is shown that a very high index of modulation can be achieved. Experimental results are reviewed for a gallium arsenide diode laser. Limitations of this technique and possible devices are considered.

201. Ripper, J. E. and T. L. Paoli
FREQUENCY PULLING AND PULSE POSITION MODULATION OF PULSING cw GaAs INJECTION LASERS. Applied Physics Letters, Vol. 15, No. 7, 1 Oct 1969, pp. 203–205.

The frequency pulling and locking of intensity pulsations from continuously operating GaAs injection lasers have been studied by varying the frequency of the externally applied locking signal in the vicinity of the self-induced pulse rate or one of its harmonics. The ability of the laser pulse rate to follow a rapidly varying locking signal has led to the first realization of optical pulse position modulation with microwave repetition rates. Modulation rates attainable with this effect are expected to be as high as one-half the self-induced pulse rate.

202. Rosen, P.
LINCOLN LABORATORY TECHNOLOGY PROGRAM IN SPACE COMMUNICATIONS. Massachusetts Inst. of Tech., Lincoln Lab., Lexington, Mass. Technical note. Rept. no. TN-1969-9. 3 Feb 1969, 16p. Contract AF 19(628)-5167. ESD TR-69-7. AD-395 659. (CONF.)

The Lincoln Laboratory has launched six satellites in the last five years. Many of the more interesting features of these satellites are incorporated in Lincoln Experimental Satellite No. 6 (LES-6). Some of these properties are discussed. A brief examination is given to the next satellite in the Lincoln series, LES-7, and some of its implicit capabilities are explored.

203. Rosen, P.
SPACE COMMUNICATIONS, DIVISION 6. Massachusetts Inst. of Tech., Lincoln Lab., Lexington, Mass. Quarterly technical summary rept., 1 Dec 1968–28 Dec 1969. 15 Mar 1969, 33p. Contract AF 19(628)-5167. ESD TR-69-48. AD-851 886.

The summary includes the work of all groups within Division 6. Communications, with the exception of the work on seismic discrimination in Group 64, and the work on submarine communication centered largely in Group 66. In these cases, the work is reported directly to the sponsors. This summary also reports on portions of the Space Communications Program undertaken by Division 7 Engineering. Detailed

planning of the LES-7 experiments and housekeeping subsystems has begun. Substantial changes are expected in the telemetry, command, and power system philosphies, relative to those employed in previous satellites. The design of novel RF circuits is being pursued with the goal of simplifying the proposed LES-7 transponder block diagram. A possible LES-7 experiment, employing a transmitter at near-visible wavelengths, is being investigated. Both the waveguide lens and the Butler array approach to the design of the LES-7 antenna have been evaluated.

204. Rosen, P. and J. M. Wozencraft
SPACE COMMUNICATIONS. DIVISION 6.
Massachusetts Inst. of Tech., Lincoln Lab.,
Lexington, Mass. Quarterly technical summary
rept., 1 Jun–31 Aug 1969. 15 Sep 1969, 33p.
Contract AF 19(628)-5167 ESD TR-69-249.
AD-861 186.

The report covers the period from 1 June through 31 August 1969 and includes the work of all groups within Division 6, Communications. Effort has centered on the Tactical Transmission System (TATS) modulation/demodulation system intended for military satellite communications. Work is continuing on the fast digital processor, the tactical vocoder, and the digital frequency synthesizer. Arrangements have been completed for the optical propagation experiment. Building modifications at each site are complete and instrumentation is being prepared for installation in order to measure the spatial and angular dependence of the multipath distribution of cloud-scattered light. LES-6 continues to operate in orbit much the same as previously reported. Much of the design philosophy of LES-7 has been agreed upon. Work continues on the X-band transponder, the attitude control subsystems, telemetry system, DC/DC converters, and command system.

205. Rosen, P. and J. W. Wozencraft
SPACE COMMUNICATIONS. DIVISION 6.
Massachusetts Inst. of Tech., Lincoln Lab.,
Lexington, Mass. Quarterly technical summary
rept., 1 Sep–30 Nov 1969. 15 Dec 1969, 38p.
Contract AF 19(628)-5167. ESD TR-69-388.
AD-866 132.

The report covers the period from 1 September through 30 November 1969. Two sets of TATS (TActical Transmission System) equipment have been tested extensively in a series of air-to-ground and ground-to-air tests using an AFSC C-135 aircraft. The most significant test during the period was the multiple-access test, in which a total

of 17 power-balanced high-rate (2400-bit/sec) TATS users (2 TATS modems and 15 simulated TATS users) operated simultaneously through LES-6. A program has been initiated to study the possibility of all-weather optical communications near the surface of the earth.

206. Rosner, R. D.
PERFORMANCE OF AN OPTICAL HETERODYNE RECEIVER FOR VARIOUS RECEIVING APERTURES.
IEEE Transactions on Antennas and Propagation, Vol. AP-17, No. 3, May 1969, pp. 324–331.

The results of an experimental study, dealing with the coherent detection of an optical signal after propagation over a 2.6-km atmospheric path, are presented. The average receiver output power was measured at the intermediate frequency for various receiving aperture diameters. The measured values were compared with predicted values calculated on the basis of no atmospheric degradations. The asymptotic approach of the received signal-to-noise ratio to a constant value for increasing aperture diameters is demonstrated and shown to be due to the turbulence in the propagation path. Typical values of the spatial coherence area are discussed.

207. Ross, M., and S. I. Green
HIGH DATA RATE OPTICAL PULSE RECEIVERS.
Fourth Conference on Laser Technology, San Diego, Jan 1970, p. 1375.

Describes a gated photomultiplier optical reciever which is gated "on" for 0.5 nanosecond intervals at 200 MBPS rate.

208. Ross, M. et al.
HIGH DATA RATE PULSED SPACE COMMUNICATION SYSTEMS. Fourth Conference on Laser Technology, San Diego, Jan 1970, p. 1357.

Compares pulse-gated binary modulation, pulse interval modulation, and pulse position modulation. Experimental TV transmission (1 channel). Presents design parameters for 200 MBPS system.

209. Ross, M.
'JUPITER CALLING...' Laser Focus,
Oct 1969, pp. 32-38.

Deep-space laser communications. Touts pulse interval modulation for 10^4 to 10^6 BPS to the outer fringes of the solar system.

210. Ross, M.
PULSE INTERVAL MODULATION (PIM)
LASER COMMUNICATIONS. Supplement to
IEEE Transactions on Aerospace and
Electronic Systems, Vol. AES-3, No. 6,
Nov 1967, pp. 324-333.

Information theory at optical frequencies, which includes quantum effects, indicates that significant advantages accrue from the use of low duty cycle, narrow pulse, high peak power laser communication systems. This system type, which employs a particular form of pulse time modulation, and is denoted as Pulse Interval Modulation (PIM), can convey many bits per pulse and employs noncoherent detection to advantage. The physical concepts underlying PIM and the philosophy of PIM are described in detail. This paper presents information efficiency in bits/joule of received energy as a function of duty cycle. This is accomplished for various error rates and bit rates. The presented data conclusively demonstrates that low duty cycle is more efficient in information transfer than high duty cycle. Specific comparisons with noncoherent and coherent PCM CW laser systems demonstrate the significant improvement factors that can be achieved with the PIM pulsed laser system. The application of PIM to deep space communications is explored and both theoretical and practical advantages are noted.

211. Ross, M., J. P. Brand, and G. M. Lee
SHORT PULSE LASER MODULATION
TECHNIQUES. McDonnel Douglas
Astronautics Co., Eastern Div.,
St. Louis, Mo. Final rept. 15 Feb
1969-15 Mar 1970. Jun 1970, 395p.
Contract F33615-69-C-1418. AFAL
TR-70-130. AD-872 051L.

212. Ross, M., S. I. Green, and J. Brand
SHORT-PULSE OPTICAL COMMUNICATIONS EXPERIMENTS.
Proceedings of the IEEE, Vol. 58, No. 10, Oct 1970, pp. 1719-1732.

Experiments in short-pulse optical communications have been performed at high data rates (10^7 bit/s) with M-ary modulation formats and, using a subnanosecond internally gated receiver, at very high data rates (2×10^8 bit/s) with binary modulation formats to experimentally verify the potential of short-pulse low-duty-cycle direct-detection formats. High resolution TV pictures and error rate data are given for two M-ary formats, pulse interval modulation and pulse position modulation; and error rate data and gated optical receiver characteristics are given for the 200-Mbit/s pulsed gated binary modulation. Results demonstrate the capability of short-pulse laser-communication systems to discriminate against background light and to efficiently convey information. Subnanosecond gating of the receiver was achieved in the 200-Mbit/s experiments. In the M-ary experiments, as many as 12 bit/pulses were transmitted, using 4095 digitally selected 1-ns time slots. High-quality TV pictures were transmitted at average detected signal to background ratios of less than 0.01.

213. Ross, M., R. Hankin, and E. Dallafior
STUDY OF COMMUNICATIONS SYSTEMS, AND DETECTION AND TRACKING SYSTEMS. DESIGN AND FABRICATION OF DYNAMIC CROSSED-FIELD ELECTRON-MULTIPLYING LIGHT DEMODULATOR. Hallicrafters Co., Chicago, Ill. Periodic Progress Report No. 2, 20 Jun–20 Sep 1964. 1964, 41p. (Contract NAS5-3777). (NASA-CR-57187). N65-18943.

This report presents results of an optical communications and tracking systems program divided as follows: Task I – analyze laser communications, detection, and tracking systems; Task II – disseminate the results of Task I through a lecture series; Task III – develop a microwave bandwidth dynamic crossed-field electron multiplier demodulator. Task I results include an analysis of laser receiver statistics and noise, a summary of noise sources with a discussion of origin and effect, and an analysis of information theory aspects wherein quantum effects of optical frequencies are considered. Equations, charts, and graphs are provided. Five lectures were given under Task II on radiation laws and statistics, noise and fluctuations, detection statistics, and information theory aspects. Task III results include construction of cylindrical geometry dynamic crossed-field electron multiplier light demodulators and preliminary measurements of frequency response.

214. Ross, M., R. Hankin, and E. Dallafior
STUDY OF COMMUNICATIONS SYSTEMS, AND DETECTION TRACKING SYSTEMS. DESIGN AND FABRICATION OF DYNAMIC CROSSED-FIELD ELECTRON MULTIPLYING LIGHT DEMODULATOR. Hallicrafters Co., Chicago, Ill. Periodic Progress Report No. 3, 20 Sep – 20 Dec, 1964. 1964, 64p. (Contract NAS5-3777).

An analysis of laser communications, detection, and tracking systems, and development work on a microwave bandwidth dynamic crossed-field electron multiplier demodulator (DCFEM) are discussed. A detailed analysis of optical receiving techniques is included. Direct photodetection and photomixing are examined. Aspects of photomixing are presented, including spatial requirements, local oscillator power requirements, and the present status of phot ixing. A comparison of photomixing and direct photodetection is made in which it is shown that the choice of a specific receiving technique must be determined for each particular application. Equations, charts, and graphs are provided. Results are given for an evaluation of factors affecting detector life and experimental data on DCFEM operation. A relatively stable detector was produced, and exhibits high current gain and good frequency response. The operating time for the tube is 100 hours.

215. Ross, M., R. Hankin, and E. Dallafior
STUDY OF COMMUNICATIONS SYSTEMS, AND DETECTION AND TRACKING SYSTEMS. DESIGN AND FABRICATION OF DYNAMIC CROSSED-FIELD ELECTRON MULTIPLY[illegible] LIGHT DEMODULATOR. Hallicrafters Co., Chicago, Ill. Periodic Progress Report No. 4 20 Dec 1964–20 Mar 1965. 1965, 20p. (Contract NAS5-3777). (NASA-CR-64425).

Results of an optical communications and tracking systems development program are presented. The microwave bandwidth dynamic crossed-field electron multiplier demodulator (DCFEM) was improved by reducing the spacing between the pedestal and secondary emission surface; this reduced the microwave drive power requirements to 1.75 watts. An evaluation of .005 mesh pedestal indicated the need for thicker

mesh; replacement of the electromagnet with a permanent magnet is being considered; and a photosurface investigation was initiated. A manual covering radiation laws and statistics, noise and fluctuations, detection statistics and information theory aspects is being prepared.

216. Rozhanskii, V. A. and Iu. A Skomorovskii
NONLINEAR SIGNAL DISTROTIONS DURING LIGHT MODULATION BY ELECTROOPTICAL MODULATORS APPLYING THE POCKELS EFFECTS [NELINEINYE ISKAZHENIA SIGNALA PRI MODULIATSII SVETA PRI POMOSHCHI ELEKTROOPTICHESKIKH MODULIATO-ROV, ISPOL' ZUIUSHCHIKH EFFEKT POKKEL'SA]. Radioteckhnika i Elektronika, Vol. 13, Nov. 1968. pp. 2095–2097. 5 refs. In Russian.

Discussion of nonlinear distortions of wideband multichannel optical signals during transmission over communication lines using electrooptical modulators based on the Pockels effect. It is found that the shape of a real optical signal transmitted over a multichannel optical line is nearly rectangular.

217. Scalise, J. and R. B. Allen
GAASP DIODE-PUMPED ND:YAG LASER, TEXAS INSTRUMENTS INC. EQUIPMENT GROUP, DALLAS TEX. Final rept. 1 Jan – 31 Dec 1969. Rept No. TI-UI-828400-1 Apr 1970, 58p. Contract F33615-69-C-1362, AFAL TR-70-49 AD-868728.

The use of spontaneous, GaAsP light-emitting diodes for CW optical pumping of Nd: YAG lasers was investigated. Two diode-pumped lasers were constructed and successfully operated at liquid nitrogen temperatures (77K). CW laser outputs of 130 mW and 430 mW were obtained at 1.06 micrometers with power efficiences of 1.23 percent and 1.02 percent, respectively. The importance of the spectral match between the laser

219. Smith, V.
EQUIPMENT FOR DEMONSTRATING PCM/PL LASER COMMUNICATION. Hughes Aircraft Co., Culver City, Calif. IN: NASA, Marshall Space Flight Center Space Opt. Technol. Conf., Vol. 2 Apr 1966 pp. 43–64.

NOTICE: Avialable to U.S. Government Agencies and Their Contractors Only.

The development of an experimental high data rate laser communication system is reported. The system is based on the Pulse Code Modulation/Polarization Modulation (PCM/PL) concept.

In this modulation technique the information to be transmitted is encoded in a PCM format, and then ones and zeros are transmitted over the laser beam as right and left circular (or elliptical) polarization. Principles of the experimental system are described, and a pictorial review of the equipment status is included.

220. Smith, C. V.
A HIGH DATA RATE LASER COMMUNICATION SYSTEM. (Institute of Electrical and Electronics Engineers, Aerospace and Electronic Systems Convention, Washington, D.C., Oct 3–5, 1966, Paper.) IEEE Transactions on Aerospace and Electronic Systems, Supplement, Vol. AES-2, Nov 1966, p. 214–224. Contract No. NAS 9-4266.

A sophisticated laser communication system has been built and tested both in the laboratory and over field distances. It is envisioned that laser systems using the same techniques might someday return real time television and telemetry from manned interplanetry spacecraft. In the breadboard system, commercial rate television, sound, and a data channel are multiplexed into a 30 × 100 bit/sec (PCM) format, and this signal is modulated onto the laser beam using polarization modulation (PL). We believe this is the first application of a high-power argon ion laser in a communication system. The paper contains an illustrated description of the system, a brief discussion of problems associated with the integration of the high power laser and the wide band modulator, and a summary of experimental results obtained under field conditions. Photographs of the TV monitor, transmitted under various atmospheric conditions, are included.

material absorption characteristics and the GaAsP array output was determined using experimental data. A computer program was developed to calculate the diode array peak wavelength necessary for maximum utilization of available pump energy by the laser rod. Restrictions imposed on the choice of pumping geometries by available discrete diode packages were determined. Based on the results of this program, design recommendations were made for improving the performance of adiode-pumped laser.

218. Shchulenin, V. P.
NONPARAMETRIC METHODS OF DETECTING LIGHT SIGNALS (NEPARAMETRICHESKIE METODY OBNARUZHENIIA SVETOVYKH SIGNALOV). IN: Conference on the Theory of Information Transmission and Coding, 4th, Tashkent, Uzbek SSR, September 29 – Oct 10, 1969, Proceedings. Section 2 – Statistical theory of signals and noise. Methods of optimal reception (Konferentsiia po Teorii Peredachi i Kodirovaniia Informatsii, 4th, Tashkent, Uzbek SSR. Sep 20 – Oct 10, 1969, Proceedings. Section 2 – Statisticheskaia teoriia signalov i pomekh – Metody optimal'nogo priema). (A70-42551 22-07) Moscow and Tashkent, Nauchnyi Sovet po Kompleksnoi Probleme Kibernetika AN SSSR, 1969, p. 237–242. 12 refs. In Russian.

Comparison of detection algorithms based on the use of nonparametric statistics for the reception of light signals on a noise background. Specific examples are given for the detection of light signals in Poisson noise and thermal noise, using locally most powerful rank tests. The observed property is the number of photoelectrons; formulas are given for photoelectron distribution in the absence and presence of signals in the noise. The form of the linear rank statistic used in each case is described, and relations are obtained for the weighting coefficients. The asymptotic efficiency of Mann-Whitney tests is compared with that of likelihood ratio detectors, and it shown that nonparametric detection algorithms have a false alarm probability which is invariant with respect to the noise distribution function.

219. Smith, V.
EQUIPMENT FOR DEMONSTRATING PCM/PL LASER COMMUNICATION. Hughes Aircraft Co., Culver City, Calif. IN: NASA, Marshall Space Flight Center Space Opt. Technol. Conf., Vol. 2 Apr 1966 pp. 43–64.

NOTICE: Avialable to U.S. Government Agencies and Their Contractors Only.

The development of an experimental high data rate laser communication system is reported. The system is based on the Pulse Code Modulation/Polarization Modulation (PCM/PL) concept.

In this modulation technique the information to be transmitted is encoded in a PCM format, and then ones and zeros are transmitted over the laser beam as right and left circular (or elliptical) polarization. Principles of the experimental system are described, and a pictorial review of the equipment status is included.

220. Smith, C. V.
A HIGH DATA RATE LASER COMMUNICATION SYSTEM. (Institute of Electrical and Electronics Engineers, Aerospace and Electronic Systems Convention, Washington, D.C., Oct 3–5, 1966, Paper.) IEEE Transactions on Aerospace and Electronic Systems, Supplement, Vol. AES-2, Nov 1966, p. 214–224. Contract No. NAS 9-4266.

A sophisticated laser communication system has been built and tested both in the laboratory and over field distances. It is envisioned that laser systems using the same techniques might someday return real time television and telemetry from manned interplanetry spacecraft. In the breadboard system, commercial rate television, sound, and a data channel are multiplexed into a 30 × 100 bit/sec (PCM) format, and this signal is modulated onto the laser beam using polarization modulation (PL). We believe this is the first application of a high-power argon ion laser in a communication system. The paper contains an illustrated description of the system, a brief discussion of problems associated with the integration of the high power laser and the wide band modulator, and a summary of experimental results obtained under field conditions. Photographs of the TV monitor, transmitted under various atmospheric conditions, are included.

221. Smith, D. A.
A FREQUENCY SHIFT KEYING METHOD OF DIGITAL MODULATION OF LASERS USING ANISOTROPIC CRYSTALS. Minnesota Univ., Minneapolis. Ph.D. Thesis, 1968 143p.
Avai. Univ. Microfilms: HC $6.80/Microfilm $3.00 Order No. 68-12305. N69-20160.

A unique optical modulation and detection technique has evolved from an investigation of methods of digital modulation, transmission, and detection in the optical region. In particular a frequency shift keying laser communication system has been demonstrated and the advantages of such a system have been shown. A detailed theoretical analysis of electromagnetic wave propagation in an electro-optic crystal of arbitrary orientation was developed. In turn the parameters for an optical modulator capable of frequency shift keying at a digital rate were determined. Based on this analysis a laboratory communication system incorporating FSK modulation and detection capabilities was built and successfully operated.

222. Smith, W. V., and D G. Carlson
RESONANT, CIRCULARLY SCANNING OPTICAL MULTIPLEXING SYSTEM. Journal of the Optical Society of America, Vol. 59, No. 1, p. 108–109, Jan 1969.

An optical resonator (parallel flat mirrors) encloses two electrooptic deflectors driven by a sinusoidal voltage. Large displacements occur because a light pluse makes passes through the deflectors. A bit rate of 10^{11} BPS could result from the example given.

223. Sommers, H. S., Jr., and E. K. Gatchell
BLIP CONDITION IN POINT-TO-POINT OPTICAL COMMUNICATION. IEEE, Proceedings, Vol. 55, Feb. 1967, p. 189-192. 7 refs.

Analysis of the signal-to-noise ratio of optical point detectors under conditions of large background radiation (BLIP detection) gives relations describing the background limit to the sensitivity of point-to-point optical communication systems. In narrowband applications, noise-equivalent-power (NEP) has a utility for study of the point BLIP detector which is equivalent to that of the detectivity D* for large area BLIP detectors; for

wide bandwidths, a more suitable parameter is the retrieval efficiency β of the receiver. Each of these is expressed in terms of D^*_{BLIP}, a quantity graphed in references on infrared detectors. A numerical example shows that even on the surface of the earth, broadband point-to-point communications may well be receiver limited rather than background limited.

224. Sonnenberg, H.
HIGH EFFICIENCY OF 1.06 MICRON PHOTOCATHODE. Fourth Conference on Laser Technology, San Diego, Jan 1970, p1035.

Until recently, the existence of efficient photoemissive detectors was confined to the visible region of the spectrum. New understanding of the physical processes of photoemission unfolds the possibility of extending efficient photoemission considerably further into the infrared region. Based on the principle of negative electron-affinity, the new understanding includes the concept of efficient photoemission utilizing a heterojunction consisting of a thin layer of low-electron-affinity n-type semiconductor-material and a p-type semiconductor-substrate.

225. Staron, M.
STUDY OF AN AUTOMATIC TRACKING DEVICE USING LASER ECHOS (ETUDE D'UN DISPOSITIF DE POURSUITE AUTOMATIQUE D'UN MOBILE UTILISANT LES ECHOS LASER).
La Recherchel Aerospatiale, Nov – Dec 1969, p. 29–40. 9 refs. In French.

An optimal law is sought for the control in elevation and azimuth of a turret carrying a pulse laser and a receiving telescope. The establishment of this law takes into account the low recurrence of the laser echos (10 per second), and the quantification of the data issued from a device consisting of five photomultipliers. A digital computer is introduced in the servoloop; its programme includes the phase of acquisition, and task into account the nominal characteristics of the missile trajectory and the risk of echo loss; it also permits the optimization of the telescope angular field and the laser beamwidth during tracking. Possible further improvements are suggested.

226. Stokes, L. S., and K. L. Brinkman
PARAMETRIC ANALYSIS OF MICROWAVE AND LASER SYSTEMS FOR COMMUNICATION AND TRACKING. Hughes Aircraft Co., Culver City, Calif. Aerospace Group. Quarterly Report, 6 Dec 1966–6 Mar 1967. 1967 123p. refs (Contract NAS5-9637). (NASA-CR-85873; P67-82; HAC-A7747; QR-6) CSCL 09F N67-31305.

The parametric analysis of microwave and laser systems for communication and tracking is to be conducted in two phases. During the sixth quarter effort was expended on refinement of portions of the methodology section and updating of the heat radiator systems section.

227. Stone, J. L.
A UNIQUE LASER DETECTOR UTILIZING THE PHOTODIELECTRIC EFFECT IN COOLED SEMICONDUCTORS. Texas Univ., Austin. Ph.D. Thesis, 1968 177p. Avail: Univ. Microfilms: HC $8.20/Microfilm $3.00. Order No. 6 68-10889 N69-22061.

A transmission line equivalent circuit was used to accurately predict the behavior of a photodielectric detector. The photodielectric receiver was used in the design of an optical communication system used to detect video rate, amplitude modulation of 9000Å infrared light source. Communication systems are described but practical considerations of the state-of-the-art utilize the phase change of a frequency modulated re-entrant cavity. A cryogenic environment was used to suppress thermally generated free carriers and to allow operation of the cavity in the superconducting mode. A 60 ohm-cm., p-type germanium sample was used to detect a video modulated 9000Å. A light source using purer samples and carefully controlling the detector design parameters indicated the possibility of bandwidths greater than 100 MHz. Applications include wide bandwidth, multi-channel information bands, secure communication links, deep space probe communications system, and a device for basic material's properties studies.

228. Sylvania Electric Products, Inc.,
Waltham, Mass.
STUDY ON OPTICAL COMMUNICATION
EXPERIMENTAL FACILITY SUMMARY
REPORT, Mar – Dec 1966. Dec 1966. 28p.
(Contract NAS8-20304). (NASA-CR-81640)
CSCL 14B. X67-12252.

NOTICE: Available to U.S. Government Agencies
Only.

A national survey was conducted to determine the optimum location for an Optical Experimental Communication Facility (OCEF). The survey is described on national, sectional, and regional levels and the undesirable weather and atmospheric condition criteria adopted for the survey are discussed. Detailed tables showing the yearly estimated dry days for candidate sites in the southest U.S. are given, and from these data nine sites are recommended for further consideration.

229. Sylvania Electric Products, Inc.,
Waltham, Mass.
STUDY ON OPTICAL COMMUNICATION
EXPERIMENTAL FACILITY, VOLUME I
Final Report 1966 118p. refs (Contract
NAS8-20304) (NASA-CR-81620) CSCL 14B
X67-12246.

NOTICE: Available to U.S. Government
Agencies Only.

A study was conducted to determine the optimum location for an Optical Experimental Communication Facility (OCEF). A site was desired which could perform two-way laser communication with a spacecraft and laser tracking with a minimum of interruption by cloud cover and other weather effects. Much of the research was devoted to the methodical application of numerical criteria in order to discard unfavorable areas to narrow down the field, and then to identify the most promising locations for the OCEF. An initial national survey eliminated all but a single territory in the southwestern U.S. which included most of Arizona and New Mexico, as well as parts of California and Texas. Of the seven candidate sites recommended for consideration, Kingston Peak, California, Guadelupe, Mountain Range, New Mexico, and Atascosa Peak, Arizona show the most promising dry-day weather records.

230. Waksberg, A.
A DUAL SCAN ACQUISITION TECHNIQUE FOR A LASER COMMUNICATION SYSTEM.
IEEE Transations on Aerospace and Electronic Systems, Vol. AES-6, May 1970, p. 407-409.

A dual scan acquisition system is described in which both the transmitter and the receiver optics scan, although at different frequencies. The condition where only one station scans appears as a special case of the general approach. Curves of acquisition time vs various parameters are calculated. The effect of range is also discussed.

231. Wallace, A., G. M. Strauss
STUDY OF LASER POINTING PROBLEM.
Final Technical Report, 3 Aug 1964 30 Jun 1965. Kollsman Instrument Corp., Elmhurst, N.Y. 30 Jun 1965, 253p.
Contract NASw-929 NASA-CR-70896; KIC-RD-000162-5) CSCL 20E. (CONF.)

NOTICE: Available to U.S. Government Agencies and Their Contractors Only.

232. Walsh, J. L., J. F. Asmus and A. F. Milton
REPORT OF THE STUDY ON OPTICALLY PUMPED LASERS AND NONLINEAR OPTICS.
Institute for Defense Analyses Science and Technology Div., Arlington, Va. Rept. No. RP-P-547, Contract DAHC15-67-C-0011, IDA/HQ 69-10842 AD-508571 (CONF.)

The present status of optically pumped solid-state lasers and nonlinear optics is examined, and needed developments for potential defense application are pointed out. Important future DOD applications include: IR missile spoofing, laser illuminators, long-range airborne imaging, combined target designator-rangefinders, eye-safe laser devices for close-support operations, and plasma heating and initial simulation experiments. The laser improvements required for such applications include; higher average

power, higher efficiency, reduced weight, greater reliability, longer life, greater wavelength diversity, improved IR perfromance, improved mode control, and greater brightness. To achieve these improvements, the problems to be overcome are so diverse that only two major R and D areas appear to have across-the-board impact; high-average-power laser technology and general laser engineering design. In many instances, the need for improvement in laser transmitters will be in inverse proportion to the improvement in detectors. Recommendations are made for work in materials, advanced technology, engineering, and detection.

233. Ward, J. H.
A BROAD BANDWIDTH DIGITAL LASER COMMUNICATION SYSTEM. (Congrès International sur les Applications des Lasers, 1st, Paris, France, Jul 18–23, 1967, Communication.) Lasers, No. 8, 1967, p. 135, 136.

Brief description of a laser communication system which is capable of handling digital data at a 30-Mbit rate utilizing a pulse-coded polarization modulation scheme and a binary-detector arrangement. Both an analysis of the optical communication link and experimental performance data are included. A block diagram of the system is discussed, and the transmitting, modulating, and receiving components are described.

234. Ward, J. H.
A NARROW BEAM, BROAD BANDWIDTH OPTICAL COMMUNICATION SYSTEM. ITT Federal Labs., San Fernando, Calif. 6 Oct 1967 129p. refs. Contract NAS8-20629. (NASA-CR-89970)N67-23685.

NOTICE: Available to U.S. Government Agencies and Their Contractors Only.

The breadboard system is described. It is capable of transmitting pulse coded polarization modulation and amplitude modulation on a cw laser beam. The bit error rate analysis is discussed at length. Laboratory and preliminary field test results are reported. The laboratory tests were conducted to determine the performance characteristics of the broadband optical communication equipment independent of the deleterious effects of propagating through a real atmosphere. The equipment revealed no

mechanical or optical instabilities. Optical component alignment, including the directing of the laser beam through the optical modulator, is of a noncritical nature. No failures of the system were observed throughout the tests.

235. Ward, J. H.
OPTICAL COMMUNICATIONS SYSTEM DESIGN AND EVALUATION. IN: Institute of Electrical and Electronics Engineers, International Conference on Communications, San Francisco, Calif., Jun 8–10, 1970. Proceedings. Vol. 1. Edited by Donald Green, New York, Institute of Electrical and Electronics Engineers, Inc. (Conference Record, Vol. 6), 1970, p. 14-3 to 14-10.

Description of a wideband digital laser communications system which performs all the functions of an operational space-to-ground link. The experimental performance of this system, operating in a real environment, is presented and correlated with theory. A simple parameter is used to describe the effect of a turbulent atmosphere on the quantitative performance of the link.

236. Ward, J. H. and M. L. Shechet
OPTICAL SUBCARRIER COMMUNICATIONS. Electrical Communication, Vol. 42, No. 2, 1967, p. 247–260. 5 refs.

Discussion of some of the basic techniques for optical subcarrier communications, outlining three systems utilizing these techniques. It is emphasized that the use of subcarriers on an optical beam provides a great measure of versatility. The approach has advantages for a number of space-oriented missions, including long-range wideband communication, spacecraft tracking rendezvous, and spacecraft altimetry and landing aids. It also allows the use today of well developed radio-frequency techniques with the advantages of the newer electro-optical technologies. An expression is given for the signal-to-noise power ratio of a modulated laser beam.

237. Warfare Systems School Maxwell, AFB Ala. SPACE HANDBOOK. Revision No. 5 of report dated Jul 1966. Jul 1967, 368p. Rept. No. WSS-1 AD-821840,

Contents: The Space Environment, Orbital Mechanics, Propulsion Systems, Flight Vehicle Power, Guidance and Control, Communications, Atmospheric Penetration, Computers, Reliability of Space Systems, Man in Space.

238. Washington, F. K. OPTICAL AND MICROWAVE COMMUNICATIONS: A COMPARISON. National Aeronautics and Space Administration, Goddard Space Flight Center, Greenbelt, Md. May 1968 46p. refs (NASA-TN-D-3984) N68-22019.

Some preliminary comparisons are made of microwave, millimeter, and optical communication systems for space communication from a spacecraft at Mars distances. An attempt is made to be realistic with regard to technology. Some discussion of thermal, quantum, and sky noise is included, as well as some discussion and analyses of microwave, millimeter wave, and optical technology; acquisition and tracking; and some mission analysis. Based on the considerations herein, it appears likely that in the radio spectrum, the S-Band is the better place to operate. However, it also appears likely that optical communication systems have the greater potential for high data rates – up to about 10^8 bps at Mars distances.

239. Washington, F. K. OPTICAL AND MICROWAVE COMMUNICATIONS – A COMPARISON. National Aeronautics and Space Administration, Goddard Space Flight Center, Greenbelt, Md. NASA, Jun 1967 46p. refs (NASA-TN-D-3984) N67-27287

Some preliminary comparisons are made of microwave, millimeter, and optical communication systems for space communication from a spacecraft at Mars distances. Thermal, quantum, and sky noise is discussed, as well as microwave, millimeter wave, and optical technology; acquisition and tracking; and mission analysis. Based on the considerations herein, it appears likely that in the radio spectrum, the S-Band

is the better place to operate. However, optical communication systems probably have the greater potential for higher data rates – up to about 10^8 bps at Mars distances.

240. Webb, W. E., and G. A. Emmons
A REVIEW OF THE ATMOSPHERIC EFFECTS ON LASER PROPAGATION. Army Missile Command Redstone Aresenal Ala Physical Sciences Lab. 12 May 1970, 27p. Rept No. RR-TR-70-8 AD-871 752

The purpose of the report is to present a review of the atmospheric effects on laser propagation. Molecular absorption by the earth's atmosphere should not present an insurmountable problem for ruby or neodymium laser systems. However, both the water vapor and the carbon dioxide present in the atmosphere strongly absorb radiation at carbon dioxide wavelengths; this may present a serious problems to systems employing carbon dioxide lasers. Clean air scattering does not seem to be a serious problem. Aerosol scattering, however, is quite severe and will, except in the clearest weather, strictly limit the operation of ground-based laser communication systems. Atmospheric turbulence also poses a serious limitation on the performance of optical communication systems. However, on the basis of the presently available data it does not seem that atmospheric turbulence will necessarily render laser communication systems unfeasible.

241. Weber, C. L.
A UNIFIED THEORY OF COHERENT DIGITAL SYSTEMS WHICH TRACK DOPPLER FREQUENCY. University of Southern California, Electronic Sciences Lab., Los Angeles. Interim technical rept. Rept. no. USCEE-374 AROD-7198:15RT. Oct 1969, 42p. Contract NASA-EW-473447. AD-699 381.

A unified theory from which the design of a large class of coherent digital communication systems can be optimally carried out is presented. In the design of digital communication systems, the error rate is the criterion which is invariable emphasized. In many digital systems, however, there is relative motion between transmitter and receiver which must be estimated by making use of Doppler frequency information. A new analysis of a general class of coherent digital systems is herein developed, in which the trade-offs that exist between Doppler measurement capability and subcarrier demodulation error rate are quantitatively presented. The theoretically unrecoverable

power loss which exists when employing frequency division multiplexing subcarriers as compared to time division multiplexing is described. The results point out that there is significant parametric dependence of the optimal choice of system parameters on the carrier loop signal-to-noise ratio and the data rate.

242. Wells, W. H.
COMMUNICATIONS AND TRACKING, AND OTHER ACTIVITIES OF THE JPL QUANTUM ELECTRONICS GROUP. Jet Propulsion Lab., Calif., Inst. of Tech., Pasadena, Calif. IN: NASA. Marshall Space Flight Center Proc. of the Space Opt. Tech. Conf., Vol. 1 Apr 1966, p. 59–65 refs. Contract NAS7-100 N68-31766.

Discussed are problems in connection with feasibility studies of a N_2-CO_2 laser at 10.6 μ for optical communication and tracking, including economic considerations that led to the choice of this wavelength. Reliability, weather dependence, and pointing accuracy of optical frequency communication systems are evaluated against the role of radio frequency communication telemetry. A table of decibels is presented and discussed which compares the possibilities of the following five wavelengths: (1) the 13 cm S band as used with the 64-m D antenna at the Deep Space Instrumentation Facility at Goldstone: (2) the 10.6 μ, generated by an efficient gas laser; (3) the 3.5 μ, included for possible future developments; (4) the 0.84 μ, generated by a compact, efficient GaAs injection laser; and (5) the 0.63 μ, generated by a helium-neon laser.

243. Welti, G. R., and S. H. Durrani
COMMUNICATION SYSTEM CONFIGURATION FOR THE EARTH RESOURCES SATELLITE. American Institute of Aeronautics and Astronautics, Communications Satellite Systems Conference, 3rd, Los Angeles, Calif., Apr 6–8, 1970, Paper 70-326. 14p. 9 refs.

The communications requirements of the earth resources disciplines and other programs for the 1970s are estimated. Several methods of providing a continuous real-time wideband communication link between the earth resources satellite and a central ground station using relay satellites are considered. The feasibility of using commercial communication satellites is examined. It is found that INTELSAT IV (to be launched in 1971) can provide data links with mission spacecraft and data collection platforms,

but that a modified INTELSAT IV would be needed for a television link. Other systems examined employ dedicated medium-altitude satellites, and shared synchronous-altitude commercial satellites. An example of a shared system is presented which is capable of serving earth resources satellites, in-situ data collection platforms, and manned space stations, as well as providing communications services to other users.

244. Westinghouse Electric Corp., Baltimore, Md. Surface Div.
ADVANCED STUDY ON OPTICAL COMMUNICATIONS FROM DEEP SPACE. Final Technical Documentary Report, 1 Oct 1964–25 Oct 1965
25 Oct 1965, 303p. refs (Contract NAS9-3650)
(NASA-CR-65355; HUD-38120; MDE-6545)
X66-18246.

NOTICE: Available to NASA Offices, Centers, and Contractors Only.

Laser communications systems requirements are developed for a manned deep-space mission and an orbiting laboratory of the Apollo extended mission type using PCM/PL, PPM, and coherent FSK modulation. Mission analyses determine the geometrical constraints and data requirements. Environmental analyses define the effects of the earth's atmosphere, the noise backgrounds, and the space radiation and particles. Functional synthesis generates gross system concepts. Functional analyses investigate the interrelationships between parameters (particularly the communications theory aspects) and develop a model for computation of requirements. Techniques investigations consider ways of implementing the hypothesized functions. Configuration synthesis blocks out systems for each of the modulation techniques and missions. Evaluation of the systems is based on transmitter power requirements.

245. Westinghouse Electric Corp., Baltimore, Md.
FM OPTICAL COMMUNICATION TECHNIQUE.
Interim engineering rept. No. 3, 1 Dec 1963 – 27 Feb 1964. 16 Mar 1964, 29p. Contract NObsr89317. AD-348 351. (CONF.)

246. Westinghouse Defense and Space Center Baltimore, Md. Aerospace and Electronic Systems Div.
GUIDANCE ILLUMINATOR AND RANGER. Final rept. 22 Dec 1967–25 Aug 1969. Aug 1969, 169p.
Contract DAAH01-68-C-1010 AD-508-370L. (CONF.)

247. White, G.
A ONE-GIGABIT-PER-SECOND OPTICAL
PCM Communications System

An optical communications system is described which is capable of transmission and detection of 1-Gb.s^{-1} pulse-code modulation (PCM) word patterns. Modulation of an argon laser beam is obtained with a lithium tantalate (LiTaO) modulator rod using a traveling-wave interaction. The high-speed electrical modulation signal is obtained by a multiplexing of four separate information channels.

248. White, G.
OPTICAL MODULATION AT GIGAHERTZ RATES.
(Bell Telephone Laboratories, Inc., Holmdel, N.J.).
In: Institute of Electrical and Electronics Engineers,
International Conference on Communications,
San Francisco, Calif., Jun 8–10, 1970, Proceedings.
Volume 1. Edited by Donald Green, New York, Institute of Electrical and Electronics Engineers, Inc.
(Conference Record. Volume 6), 1970, pp. 22–38 to
22–45, 20 refs.

An optical communications system is described which is capable of transmission and detection of a 1 gigabit per sec optical PCM word pattern. The high speed optical modulation is obtained in a traveling wave manner, in a lithium tantalate modulator crystal. The electrical modulation signals are provided by a PCM system which makes use of a gating and multiplexing process to achieve the high information rate.

249. Whitman, A. M., and M. J. Beran
BEAM SPREAD OF LASER LIGHT PROPAGATING
IN A RANDOM MEDIUM. Optical Society of America,
Journal, Vol. 60, Dec 1970, pp.1595–1602. 10 refs.
Research supported by the Pennsylvania Science and
Engineering Foundation.

We consider here the beam spread of laser light when it propagates in a random medium. The analysis is given in terms of the coherence function. Explicit results are obtained principally for the region of multiple scatter. In this region, it is shown

that the irradiance pattern is always Gaussian and that the characteristic beam diameter increases at a rate proportional to z super 3/2, where z is the propagation distance. The proportionality constant is determined for an arbitrary index-of-refraction spectrum, and the Kolmogorove spectrum is given as a special case. The results obtained are considered in atmospheric and oceanographic application.

250. Whitmer, R. F.
A GIGAHERTZ BANDWIDTH SATELLITE-TO-SATELLITE DATA RELAY SYSTEM. Fourth Conference on Laser Technology, San Diego, Jan 1970, p. 1391.

Compares microwave and laser systems for 1000 MHz bandwidth 30 db SNR space – space communication.

251. Whitmer, R. F., R. C. Ohlmann, H. V. Hance, and K. F. Cuff.
ULTRA-WIDE BANDWIDTH LASER COMMUNICATIONS: Part I – System Considerations for a Satellite Link. Proceedings of the IEEE, Vol. 58, No. 10, Oct 1970.

A design concept for an optical data relay link between two earth satellites is presented for missions requiring ultra-wide information bandwidths, 100 to 1000 MHz, and detected signal-to-noise ratios greater than 30 dB. Only analog modulation is considered owing to the inherent complexity in digitizing analog data of the bandwidths of interest. The optical system is compared to a microwave system on the basis of the primary power required at the transmitter, using system and component characteristics likely to be achieved with a moderate development effort. The conclusion is that an optical system will require an order-of-magnitude less power than the best microwave system.

252. Williams, R. M.
LASER ELECTRO-OPTICAL NAVIGATION SYSTEM. In: National Aerospace Electronics Conference, 17th, Dayton, Ohio, May 10–12, 1965, Proceedings. Conference sponsored by the Professional Group on Aerospace and Navigational Electronics, Dayton Section of the Institute of Electrical and

Electronics Engineers, and American
Institute of Aeronautics and Astronautics.

Dayton, Institute of Electrical and Electronics
Engineers, Dayton Section, 1965, pp. 120-125.
11 refs.

Detailed feasibility analysis of a satellite-borne electro-optical angular tracker and a well surveyed earth-based corner-reflector sensor system. The sensor system includes a laser system for illuminating the corner reflector, an amplitude-comparison photomultiplier system for corner-reflector acquisition and tracking, and an interferometer fine-track sensor. Tracking accuracies of 5 μ rad are postulated for the amplitude-comparison tracker, ignoring atmospheric effects, and 0.5 μ rad for the 1-ft-baseline interferometer tracker.

253. Wischnia, H. F., H. S. Hemstreet, and
J. G. Atwood
DETERMINATION OF OPTICAL TECHNOLOGY
EXPERIMENTS FOR A SATELLITE. Perkin-Elmer
Corp., Norwalk, Conn. Washington, NASA, Jul
1965 360p. refs (Contract NAS8-11408) (NASA-
CR-252) N65-28806.

Experiments to be conducted in an earth satellite vehicle which will best advance the development of optical technology in space are presented. The field of consideration was limited to optical communication and certain closely related general aspects of optical astronomy and optical scientific instrumentation in space. Thirteen experiments were recommended divided into five subgroups: atmospheric, eye-hand loop, heterodyning, tracking and acquisition, and communications. The following are discussed in detail: Atmospheric Scintillation; Atmospheric Effects on Polarization; Remote Manual Optical Alignment; Optical Heterodyne Detection in the Satellite; Optical Heterodyning on Earth; One-Tenth Arc-Second Tracking Demonstration; Point-Ahead; Space-to-Ground-to-Space Loop Closure; Tracking Demonstration in the Presence of Spacecraft Motion; Suspension Systems Comparison; Tracking Transfer Demonstration from Ground Station A to Ground Station B; Earthshine Effects on Acquisition and Tracking; and Communication at 10^7 CPS.

254. Wischnia, H. F.
DETERMINATION OF OPTICAL TECHNOLOGY EXPERIMENTS FOR A SATELLITE, PHASE II. Engineering Report No. 7924. Electro-Optical Div., Perkin-Elmer Corp., Norwalk, Conn. (Contract NAS8-11408) (NAS-CR-62340) N65-22174.

Earth satellite experiments are recommended which would advance the technology associated with deep space optical communications and diffraction limited optical systems in space. Block diagrams and further system analysis of experiments selected are presented. Also, the key issues of aperture and its effect on channel capacity for a deep space optical communication system were evaluated for a number of crucial parameters. Further, the laser communication performance curves were computed for diameters of 9, 16, 32, and 64 inches for quantum efficiencies of the detector equal to 8% and 100%. The calculations of channel capacity were concluded to provide a communications breakthrough over microwave communication systems. For a 32-inch aperture system, with a 100-milliwatt laser, the channel capacity was 5.2×10^6 bits/sec for 100% quantum efficiency of the sensor, or 0.42×10^6 bits/sec for a quantum efficiency of 8%.

255. Wischnia, H. F.
LASER COMMUNICATION SATELLITE EXPERIMENT (LCSE). Perkin-Elmer Corp., Electro-Optical Div., Norwalk, Conn. 1 Jul 1966 176p. refs Its Rept. 8399 (NASA-CR-74462) CSCL 20E N66-35171.

Equipment for the Laser Communication Satellite Experiment (LCSE), and experimental procedures for the experiment are described. Also described are the functions of the LSCE laser/telescope; Apollo Spacecraft modifications for the LCSE; and technical requirements and parameters for components of the LCSE. Calculations of the expected power requirements for the space-to-earth communication link are presented. Information is also given for Ground Station PCM/PL receiver and tracker; and types of data to be developed from the experiment are discussed. The pre-flight, in-flight, and post-flight time requirements allotted the astronauts are outlined, along with a cost and schedule summary. Data tables and curves, and illustrative diagrams relating to the LCSE are included.

256. Wittmann, H. R.
AN ERBIUM LASER TARGET ILLUMINATOR PUMPED BY GALLIUM ARSENIDE LIGHT EMITTING DIODES. Army Missile Command Redstone Arsenal Ala Physical Sciences Lab. 18 May 1970, 16p. Rept. No. RR-TR-70-10 AD-871 753.

The design of a 1 megawatt Q-switched erbium laser range-finding or target illumination system pumped by an array of electroluminescent, amphoterically doped gallium arsenide diodes is outlined. As the absorption spectrum of the laser rod is matched with the emission spectrum of electroluminescent diodes, a conversion efficiency of electrical into lasing energy of 1 percent is achieved. No liquid or other active cooling system is required for repetition rates below 30 pulses per second. The weight of the system is estimated to be below 2.5 kilograms.

257. Wood, L. E., M. C. Thompson, Jr., and J. B. Jones
EXPERIMENTAL STUDIES OF ATMOSPHERIC EFFECTS ON RADIO AND OPTICAL SIGNALS. In: Laser applications in the geosciences; Douglas Advanced Research Laboratories, Symposium, Huntington Beach, Calif., Jun 30-Jul 2, 1969, Proceedings. Edited by J. Gauger and F. F. Hall, Jr. North Hollywood, Calif., Western Periodicals Co., 1970, pp. 97-107, 13 refs.

Results of measurements of the correlation between the variabilities of the microwave refractive index and the microwave-optical dispersion measured over tropospheric paths. The wavelengths used were 3.2 cm for the micrwave and 6328A for the optical. The paths were a 65-km overwater slant path and a 15-km nearly horizontal path over land. The correlations obtained are heavily concentrated near unity, indicating that the dispersion variability closely approximates the microwave index variability. Applications of the technique are described.

258. Wyman, C. L.
AN ADVANCED LASER TRACKING TECHNIQUE FOR FUTURE SPACE GUIDANCE SYSTEMS.
American Institute of Aeronautics and Astronautics, Guidance, Control, and Flight Mechanics Conference, Princeton, N.J., Aug 18–20, 1969, Paper 69-870.
8p. 7 refs.

Description of an advanced laser tracking technique for future space, guidance systems utilizing single mode diffraction limited GaAs lasers, precision laser beam deflectors, and an ultralinear image dissector. A 0.1 deg laser beam and a 0.1-deg instantaneous field of view are scanned synchronously over a 30 by 30-deg acquisition field. Once acquired, a target will be illuminated and tracked anywhere within the 30 by 30-deg field. The particular setup described is directed toward cooperative rendezvous, docking, and stationkeeping applications.

259. Yamashita, E., and Atsugi, K.
A PROPOSED MICROWAVE STRUCTURE AND DESIGN METHOD FOR THE TRAVELING-WAVE MODULATION OF LIGHT. IEEE Transaction On Microwave Theory and Techniques, Feb 1969, pp. 118–119.

A shielded three-medium strip line is proposed for the traveling-wave microwave modulation of light. The microwave velocity of this structure is evaluated based on a variational formula. Numerical values are presented for the case of a line comprising layers of carbon disulfide, glass, and air.

260. Yura, H. T.
THE SECOND-ORDER RYTOV APPROXIMATION. Rand Corp., Santa Monica, Calif. Feb 1969, 16p. Rept. No. RM-5787-PR Contract F44620-67-C-0045 AD-684 122.

An explicit and useful formulation of the solution for the second-order Rytov approximation is given. From this solution a condition of validity for the Rytov solution is obtained. It is concluded that, in general, both the Born and Rytov approximations have the same domain of validity.

261. Young, L., ed.
ADVANCES IN MICROWAVES, EDITED
BY LEO YOUNG, STANFORD RESEARCH
INSTITUTE, NEW YORK, ACADEMIC
PRESS, 1970.

Contents: High-speed photodetectors for microwave demodulation of light.

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